# An Assessment of the Risks of Gambusia infestation in Tasmania

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*Report to NRM North, Tasmania*

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## Executive Summary


This report describes a descriptive and qualitative risk assessment of the risks of Gambusia infestation to Tasmanian aquatic ecosystems and related values. The following conclusions have been drawn.

*Infestation risk*

- Extensive areas are at risk of potential infestation of Gambusia in Tasmania. Most river, wetland, waterbody and estuarine systems are suitable for establishment of Gambusia populations once introduced. The risk of infestation is high statewide in the medium to long term, and presents a high and spatially extensive hazard to the state's aquatic ecosystems.
- Most aquatic habitats in Tasmanian are likely to ultimately contain and sustain Gambusia populations if control is poor. Infestations will be more substantial and widespread in lowland and coastal, shallow wetland, lagoon, farm dam, estuary and saltmarsh habitats.
- The rate of Gambusia dispersal will vary greatly. In the absence of human translocation it will be slow between catchments. Local dispersal within catchments could be relatively fast in downstream directions. Cooler temperatures and higher flow velocities will limit the rate of dispersal and establishment and the intensity of new infestations in western and upland areas.
- Human translocation remains the single most likely route of introduction to uninfested aquatic assets.
- All lowland wetlands, lagoons and lakes are rated at moderate to high risk of Gambusia infestation. Upper elevation lentic habitats are rated at low to moderate risk, but are not rated as having no risk.
- Most lowland river catchment mainstem channels across the state are at moderate to high risk of Gambusia infestation. Larger tributaries are rated at low to moderate risk, while all smaller tributaries are rated at low risk.
- All mapped estuarine and saltmarsh assets are rated at moderate to high risk.

- Several extensive wetland and saltmarsh complexes have the potential to develop into substantial nodes of infestation.

*Consequences*

- Consequences of Gambusia infestation are likely to be variable, depending on habitat and the presence of vulnerable species.
- The combination of high and widespread infestation potential with locally intense consequences leads to a high overall risk from Gambusia to aquatic ecosystem biodiversity, frog community conservation status and the conservation status of up to 7 native endemic fish species.
- Consequences of severe infestations for nearly all frog species are likely to be severe. Consequences for fish species are variable. All listed Galaxiid and Paragalaxiid species are likely to be vulnerable to Gambusia predation and competition.
- Impacts on aquatic ecosystem benthic and water column invertebrate communities may be severe in highly infested, shallower waters.
- Risks to socioeconomic values are likely to be low to moderate, but may occasionally be locally high.
- Large scale impacts on recreational or commercial fisheries are unlikely. Local impacts on shallow water lowland and coastal recreational fisheries for trout are most likely.
- Localised impacts on social amenity and aesthetic values could occur through changes in water quality and perceptions related to Gambusia presence in waters of public amenity, high visibility or conservation areas.
- Increased costs associated with management of other species may include mitigation costs and increased fish translocation costs.

*Management commentary*

- General comment is provided on the current control program and activities.
- Several management and research recommendations are made aimed at adding value to the current program (see Sections 8 and 9 for details).

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## 1. Introduction and Aims

*Gambusia holbrooki* is a highly invasive alien fish species now established in all Australian states. In Tasmania, introduction occurred in the early 1990's to the Tamar estuary area. This infestation has been the subject of an ongoing program of attempted eradication and control over the last decade. A risk assessment was requested in order to inform funding decisions around the program's continuation from 2012 onward. This document reports on that risk assessment.

The aims of this project were:

1. to conduct a Risk Assessment to evaluate:
   - the potential Tasmanian distribution of *Gambusia holbrooki*
   - the potential impacts on native fauna, aquatic systems and human values
   - the likelihood of dispersal beyond the Tamar estuary and local catchment and the greater South Esk Basin
2. and in doing so, to also provide:
   - a summary evaluation of the invasiveness of *Gambusia holbrooki*
   - an assessment of the efficacy of the current trapping program in reducing the likelihood of spread of the species.

The Gambusia infestation in the Tamar estuary has been managed under an evolving program (hereafter 'the control program') under the oversight of NRM North and Tamar NRM, and managed by a Gambusia Working Group and Project Manager, for nearly a decade. A Control Strategy for the Tamar estuary infestation has recently been initiated (Scurr 2010).

This risk assessment aims to provide the context of the potential statewide risk of Gambusia infestation within which this program and strategy sits. It does not constitute a program review (already conducted by Thorpe and Cattanach 2011), but does provide general comment on the efficacy of the program control activities and some recommendations for improvement and/or refinement.

## 2. Methodology

The risk assessment was required to assess the potential for further infestation of *Gambusia holbrooki* (hereafter referred to as Gambusia) across Tasmania and its potential impacts. This assessment differs from previous risk assessments conducted in relation to alien or exotic pests (including fish). Large scale risk assessments have been conducted at national and continental scales in the USA, Europe and Australia to assess the relative risks of a range of exotic species to invade the aquatic environment (examples include: Risk Assessment and Management Committee 1996; Kolar and Lodge 2002; Copp et al. 2005; Webb 2006; UK TAG 2009; Shine et al. 2010; Dahlstrom et al. 2011; Verbrugge et al. 2012). These are necessarily broad-brush and qualitative and generally examine relative risk between species rather than absolute risk of individual species. An Australian example is the assessment for the Murray Darling Basin reported by Clunie et al. (2002). These assessments also generally do not consider the case where a single locus of infestation has already become established, as in this analysis.

Smaller scale assessments generally consider local habitat features and associated dispersal and impact risks within quite small areas, and often in relation to current management. The most pertinent example of such a risk assessment is that conducted by Lynch (2008) for the Tamar estuary Gambusia threat. Lynch developed a check-list based risk assessment to assess suitability for Gambusia establishment at individual sites within the Tamar estuary.

The current risk assessment had to consider:

- The potential for spread across the range of aquatic habitats and habitat types present in Tasmania, and the consequences of that spread;
- The current level of management of the existing infestation;
- The experience of the existing control program, as well as Tasmanian jurisdictional (management) responsibilities and relationships.

There are no existing risk assessment methods which specifically address this situation.

Risk assessments of non-native species tend to be qualitative or semi-quantitative, mainly because the data required for quantitative assessments are lacking (Dahlstrom et al. 2011, Heikkilä 2011, Kulhanek et al. 2011). A *quantitative* and probability-based risk assessment could not also be applied for this study due to, among other things:

- Lack of detailed information on several habitat features of aquatic ecosystems across Tasmania, especially connectivity (for wetlands and wetland complexes), flow velocities (for river channels) and temperature regimes;
- Lack of specific information on the nature and intensity of the impact of Gambusia on Tasmanian native freshwater biota, for varying levels of population density and for a range of habitat characteristics (e.g. aquatic plant density).

Human translocation is a major means of Gambusia dispersal across the landscape, from global and national to local scales. Deliberate translocation of Gambusia in Australia is often done in ignorance of the hazard posed by the species and/or covertly, and without the knowledge of relevant jurisdictions. The timing and location of unofficial human translocations cannot readily be predicted or modeled, as they are often driven by loose social networks and connections, perceptions relating to mosquito infestation and control, and by chance. Human translocation of Gambusia can occur over small distances, if influenced by local proximity to a readily available source, or very large distances, if associated with personal connections between community members. This form of dispersal cannot reliably be incorporated into a quantitative risk assessment.

Taking these issues into account, a more descriptive *qualitative* risk assessment has therefore been conducted, using the general approach developed by Hobday et al. (2007) in the qualitative Level 1 SICA (Scale, Intensity, Consequence Analysis) component of the ERAEF (Ecological Risk Assessment for the Effects of Fishing) methodology for marine fisheries (see Figure 1). This aims to aims to identify which hazards could lead to a significant spread of infestation and what are the consequences (impacts) on any species, habitat or biological community. This analysis is done for whole ‘components’ (habitat types, species and communities) and is used here as a screening tool to provide general conclusions about the level and nature of risk posed by Gambusia to Tasmania’s aquatic environment, and its socio-economic impacts.

When applied to this Gambusia risk assessment, the SICA process follows these steps:

Step1: Source relevant information and describe relevant criteria for assigning the level for varying habitat types/locations.

Step 2: Rate the spatial scale(s) of the overall hazard of Gambusia infestation.

Step 3: Rate the temporal scale(s) of the overall hazard of infestation.

Step 4: Identify components (habitat types, species and communities) most likely to be affected by Gambusia infestation.

Step 5: Map and rate the intensity of the infestation for the components.

Step 6: Score the consequence resulting for the component.

Step 7: Summarise the confidence/uncertainty for the consequence ratings.

Step 8: Summarise the results and the implications for the control program.

These steps were further combined into the following sequence for this analysis:

*1. Sourcing information (Step 1)*

Compilation available literature and information relating to the characteristics of Gambusia that relate to its potential invasiveness and impacts, the history of the infestation in Tasmania, and reports and data that relate to control and eradication activities in Tasmania since infestation was detected. In addition various experts, managers and participants in the management activities relating to the Tasmanian Gambusia infestation were consulted.

*2. Identifying and rating hazard criteria (Steps 1 – 3)*

Criteria were identified that relate to the risk (hazard and consequence) of Gambusia infestation in Tasmania. These criteria were then rated in relation to the potential for infestation across the range of aquatic habitats in Tasmania, and for potential of Gambusia infestation to cause ecological and socio-economic harm. The temporal and spatial scales most relevant to the ratings were identified. Habitat types and characteristics were identified using the CFEV (Conservation of Freshwater Ecosystem Values) spatial database (DPIW 2008). This database contains GIS layers with all units or 'assets' of river channels, wetlands, lakes and lagoons ('waterbodies'), estuaries and saltmarshes, mapped at the 1:25 000 scale. Each asset is attributed with a wide range of data relating to the asset's physical characteristics, its natural biota, its biophysical condition, its 'special values' (threatened and priority species and communities etc.) and its relative conservation value.

*3. Mapping infestation risk (Steps 4 – 5)*

The combination of criteria was used to identify the relative level of infestation hazard for each habitat type – focusing on rivers, lakes ('waterbodies' in the CFEV database), wetlands, estuaries and saltmarshes – and vulnerable aquatic species and communities. The levels of hazard were then attributed to the CFEV GIS spatial data layers (using ArcGIS and specific CFEV attributes) for rivers, waterbodies, wetlands, estuaries and saltmarshes, to provide maps of infestation hazard.

*4. Consequences and Risk (Steps 6 – 7)*

In the absence of specific local data on infestation consequence, a generalized description of possible impacts of Gambusia infestation in each habitat type and for vulnerable species was prepared, with an assigned rating. The overall risk (as a product of hazard and consequence) to environmental and socioeconomic values was then assigned qualitatively and described.

*5. Implications for the control program (Step 8)*

The implications for the control program were then explored, and some recommendations made on the focus, resourcing and institutional arrangements required for the program to limit and/or mitigate the risk of Gambusia infestation.

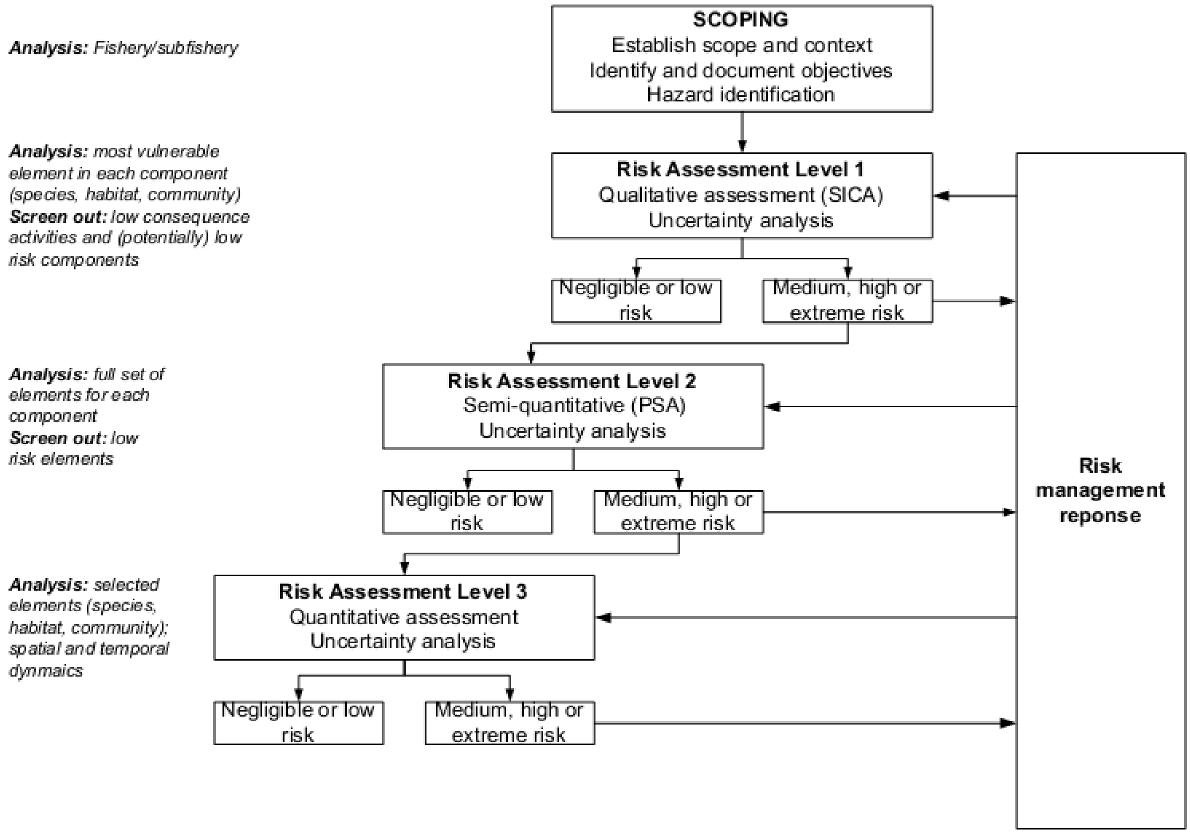


**Figure 1. Overview of the ERAEF process, showing focus of analysis for each level at the left in italics (Hobday et al. 2007).**

## 3. Species Characteristics

A large body of literature exists pertaining to the ecology of *Gambusia holbrooki* and *G. affinis*, much of which also addresses the invasion by Gambusia of aquatic habitats globally, including Australia. Key Australian references, which summarise the international and Australian literature, include the reviews and risk assessments done by Pyke and White (2000), Clunie et al. (2002), Rowe et al. (2008) and Macdonald and Tonkin (2008). This report does not provide more than a summary of those key points raised in these documents that are relevant to the hazard and possible consequences posed by Gambusia infestation in Tasmania, and readers are encouraged to read the original sources for additional information.

The following is a summary of key points relating to the potential for Gambusia infestation and impacts, drawn primarily from the excellent reviews by Rowe et al. (2008) and Macdonald and Zonkin (2008):

*Description*: Gambusia holbrooki is a small (typically 10-30 mm and less than 80 mm long), fusiform fish. Head and mouth features facilitate feeding near the water surface. Conical teeth and short digestive system support a predatory carnivorous diet (Pyke 2005).

*Habitat preferences*: Gambusia favours warm, shallow, marginal waters of lakes, ponds and wetlands and backwaters and weedy margins of streams and rivers (Casterlin and Reynolds 1977). It also occurs in saline, mangrove-swamp and saltmarsh habitats in bays and estuaries (Rowe et al. 2007).

G. holbrooki is a poor swimmer and prefers still over flowing water habitats: water velocities of around 25 cm/s and greater limit its movement (Plaut 2002). Water velocity barriers (rapids, weirs, chutes and falls) limit upstream dispersal. In river systems it is generally confined to still-water microhabitats along margins of slow-moving reaches (Lloyd et al. 1986). High winter discharges flush Gambusia out of river reaches, greatly reducing population sizes (Pusey et al. 1989; Chapman & Warburton 2006), while flow regulation can favour Gambusia (Bunn & Arthington 2002).

Gambusia prefers shallow water generally less than 15 cm and often 1-5 cm deep, often along pool edges of pools and open waters (Arthington 1988). Large individuals associate more with the bottom of macrophyte beds than the water surface (Stoffels and Humphries 2003). Gambusia is found in Australian salt lakes and thermal springs (Arthington and Lloyd 1989).

*Movement*: Gambusia does not actively migrate; some seasonal movement by over-wintering females can occur to deeper waters of lakes and ponds in late autumn (Pyke 2005). Downstream movement generally is a consequence of or follows physical displacement by floods (Haq et al. 1992). Large female

Gambusia show a preference for downstream movement, relative to small fish, and tend to be principle colonisers of new habitats within a river system (Robbins et al. 1987).

*Temperature*: G. holbrooki occurs naturally in locations where summer water temperatures range from 15-35°C (Froese and Pauly 2007). The critical thermal maximum temperature for G. holbrooki is 38°C and the preferred temperature increases with acclimation (Al-Johany and Yousuf 1993). Low water temperature limits growth and reproduction (Pyke 2005). In Tasmania, G. holbrooki start growing when temperatures exceed 19°C and no growth occurs under 15°C (Keane and Neira 2004). The optimum temperature for growth of G. holbrooki is 25°C (Pyke 2005). The onset of reproduction is limited by temperature and begins over 15°C (Medlen 1951; Pen and Potter 1991; Keane and Neira 2004).

*Salinity*: Gambusia tolerates fresh to highly saline water, but not abrupt transfers between fresh and salt water (Nordlie and Mirandi 1996; Congdon 1994b). Gambusia live in concentrations of up to 30 g/l NaCl (a salinity of c. 30 ppt) in salt lakes (Chessman and Williams 1974); Morgan et al. (2004) observed populations in 60 ppt salinity, close to the lethal (LC50) level (Chervinski 1983).

*Water quality*: Gambusia can survive concentrations as low as 1.3 mg/l dissolved oxygen without air gulping (Odum and Caldwell 1955). Below 1 mg/l, mortality increases unless air gulping at the surface is possible. Froese and Pauly (2007) reported a pH tolerance for Gambusia of 6 – 8 units. Tolerance to a wide range of chemical pollutants and biocides is high compared to other fish species (Pyke 2005).

*Predators*: In North America, Gambusia is prey for catfish, bass, herons, egrets, bitterns, grebes, ducks, and kingfishers, several snakes and invertebrates including backswimmers, water boatmen, diving beetles, dragonfly larvae and water spiders (Suhr and Davis 1974; Meffe and Snelson 1989; Swanson et al. 1996). In Australia, Gambusia is a prey species for native fish including eels, gudgeons, spangled perch, and mouth almighty (Lloyd 1984; Arthington et al. 1986); for redfin perch and the little black cormorant (Morgan et al. 2002; Boulton and Brock 1999); marron and yabbies (Beatty 2006); water rat (Hydromus) and fish eating bats (Lloyd 1984). In New Zealand, G. affinis is preyed on by eels and rainbow trout (Chisnall 1989; Rowe 2003). G. holbrooki reduces activity and food consumption in the presence of large piscivorous fish (Rehage et al. 2005b), lowering its susceptibility to fish predation.

*Feeding and prey*: Aquatic invertebrates (e.g. caddis, mayfly, midges and mosquito larvae) and zooplankton are a primary food source (Cadwallader 1979; Bence and Murdoch 1986; Arthington 1988; 1989a; Mansfield and

McArdle 1998; Garcia-Berthou 1999; Margaritora et al. 2001; Blanco et al. 2004).

Gambusia also feed on amphibian and fish eggs and larvae and are cannibalistic (Pyke 2005). Impacts on small native fish involve predation on eggs and larvae, aggression and fin-nipping leading to spatial exclusion, and competition for food (Arthington and Lloyd 1989; Gill et al. 1999; Caiola and de Sostoa 2005).

Gambusia are best described as opportunistic or generalist omnivores, as it also consumes filamentous algae and plant and fruit tissues (Arthington and Marshall 1999; McKay et al. 2001; Maynard et al. 2008).

In macrophyte habitats, G. holbrooki feeds mostly in the water column on zooplankton and plant-associated animals (Blanco et al. 2004). In open water lacking macrophyte cover, feeding is focused on benthic invertebrates and detritus. A shift from benthic feeding to feeding on zooplankton in the water column also occurs at higher Gambusia densities.

*Maturation, spawning and fecundity:* Females store sperm (Krumholz 1948), and several broods may be fertilised and incubated from a single insemination. Gambusia are oviparous fish: eggs hatch within the brood pouch, and larvae are released directly. Breeding is from spring to autumn, peaking when water temperatures are high (Pyke 2005). Little or no reproduction occurs if water temperatures are below 16°C year-round (Medlen 1951). Both water temperature and photoperiod control the timing of (Pyke 2005), with a required minimum day length of ca. 12.5 hours (Pen and Potter 1991). Juveniles first occur in November in Tasmania (Keane and Neira 2004), rarely earlier (Scurr pers. comm.).

Temperatures over 16°C and day lengths over 12-13 hours are required to initiate insemination of females, egg incubation and hatching (Pyke 2005). Reproduction ceases once day length falls below ca. 13 hours (Brown and Fox 1966).

Females carry on average 40-60 eggs per brood (Froese and Pauly 2007); the maximum reported is 375 (Pyke 2005). Keane and Neira (2004) reported a range of 3-144 eggs per female in Tasmania, with a mean of 55.5.

Gestation is dependent on temperature and ranges from 15-50 days (Pyke 2005) up to 34 days in Tasmania (Keane and Neira 2004). With a gestation of 3-5 weeks, and a delay between birth and fertilisation of the next litter of about a week, Gambusia could reproduce every 4-6 weeks, producing multiple broods per year (Pyke 2005), to a maximum number of ca. nine (Milton and Arthington 1983, Pyke 2005).

Froese and Pauly (2007) indicated a population doubling time for Gambusia of about 15 months. Females generally die in autumn following the summer in which they reach maturity (Krumholz 1948; Pen and Potter 1991).

*Population size and structure*: Large aggregations (hundreds per $m^2$) can occur in the surface waters of wetlands, lakes and ponds in summer, especially in shallower well-lit and warmer margins.

*Introduction and impacts in Australia*: Clunie et al. (2002) provide a comprehensive account of the initial introduction and subsequent spread of Gambusia in Australia. Gambusia is now well established across Australia and its geographic distribution is slowly expanding. It is expected to eventually colonise all suitable habitats. Gambusia has been implicated in the decline of 10 species of frog and between 9 and 20 species of native fish in Australia (MDBC 2007; Queensland DPI 2007). These declines are believed to be due to the combined effects of predation on eggs, larvae and tadpoles, food competition, fin nipping (and associated condition decline) and aggressive behavioural interactions (Gillespie and Hero 1999; Pyke and White 2000; Rowe et al. 2008). These mechanisms vary substantially by season, habitat type, level of plant cover, Gambusia density and the species and density of prey. Native fish distributions within habitats are also changed through interactions with Gambusia, though long term implications of such changes are unknown (Arthington and Lloyd 1989).

In summary, Gambusia's aggressive nature, fast maturation and high reproductive rates, flexible behaviour and broad environmental tolerance make it a highly successful invader. It is considered to pose a serious threat to native fish and frogs in Australia and overseas (Courtney and Meffe 1989; Howe et al. 1997; Gillespie and Hero 1999; Caiola and de Sostoa 2005; Rowe et al. 2008). Gambusia has now been implicated in the local or overall decline of populations of some 20 species of Australian native fish and up to 15 species of Australian frogs; 5 and 5 of these, respectively, are Tasmanian species (Table 1). These conclusions were drawn from either tank-based experiments on fish or tadpole susceptibility to predation by Gambusia, or field-based studies examining changes in local or regional fish or frog geographic distributions in relation to the spread of Gambusia (Table 1), along with observations of a range of physical impacts and population trends.

**Table 1. Existing published evidence for impacts of Gambusia on Tasmanian native fish and frog species. Studies are categorised into those providing 'field-based' or distributional evidence for an adverse effect (e.g., mutually exclusive distributions, fin-nipping, dietary overlap), and those providing information on potential mechanisms of impact by way of experimental 'tank-based' or enclosure studies. (Adapted from Rowe et al. 2008).**

| Common name | Scientific name | Studies on impacts | |
|---|---|---|---|
| | | Field-based | Tank-based |
| **Fish** | | | |
| Australian smelt | Retropinna semoni | 1, 2 | |
| Southern pygmy perch | Nannoperca australis | 3 | 4 |
| Common jollytail | Galaxias maculatus | | 5 |
| Dwarf galaxias | Galaxias parvus | 7 | |
| Eastern little galaxias | Galaxiella pusilla | 6 | 4 |
| **Frogs** | | | |
| Common froglet | Crinia signifera | | 8, 10 |
| Green and golden bell frog | Litoria aurea * | 13, 15 | 12, 14 |
| Southern brown tree frog | Litoria ewingii | 9 | |
| Spotted marsh (grass) frog | Limnodynastes tasmaniensis | | 11 |
| Striped marsh frog | Limnodynastes peronii | | 10 |

1 Williams (1971), 2 Arthington et al. (1981), 3 Lloyd and Walker (1986), 4 Koster (1997), 5 Becker et al. (2005), 6 Unmack and Parras (2007), 7 Morgan and Gill (2004), 8 Williamson (1988) cited in Morgan and Buttemar (1996), 9 McGilp (1994), 10 Webb and Joss (1997), 11 Harris (1995), 12 Morgan and Buttemer (1996), 13 White and Pyke (1996), 14 Pyke and White (2000), 15 Hamer et al. (2002a).

* Not a Tasmanian species but closely related genetically and ecologically to Litoria raniformis and only taxonomically separated since 1975.

Tasmanian fish occupying shallower wetland and slow flowing environments are likely to be particularly at risk. Observations during the Tamar Gambusia control program indicate that fin nipping and/or predation on the Growling Grass Frog (aka the Green and Gold frog, Litoria raniformis) also occurs, as well as several Galaxiid and estuarine fish species including hardyheads, gobies, pygmy perch (Nannoperca australis).

## 4. **Hazard criteria for the spread of Gambusia in Tasmania**

Several key characteristics are significant in terms of the hazard posed by Gambusia to Tasmanian aquatic ecosystems:

*Habitat requirements:* Broad habitat and environmental tolerances meaning that the species can complete its life history within a wide range of aquatic habitat types present across Tasmania;

*Dispersal ability:* the degree to which the species could disperse naturally across the aquatic landscape, both within and between catchments and habitats;

*Life history:* the species' high reproductive rate under most conditions, and the availability of suitable conditions for completing its life history across Tasmania's aquatic landscape;

*Feeding:* the presence of a wide range of appropriate prey;

*Predation and competition*: evidence of predatory control of Gambusia by other species found in Tasmania.

These characteristics are discussed in more detail below and presented, along with hazard ratings, in Table 2.

### *4.1 Habitat requirements*

Gambusia populations are known from a very wide variety of habitat types elsewhere, which encompasses all stream, lake, wetland and estuarine freshwater habitat types and conditions found in Tasmania. While the species favours slow-flowing, still and shallower habitats, often with well-developed aquatic plant communities, populations are known from a wide variety of less optimal habitat types.

A key aspect of the species' preferred habitat is the temperature regime, with the highest Gambusia densities recorded in habitats with warmer summer temperatures. It is also known in waters which freeze during winter however, as well as waters with poor water quality (high turbidity, low dissolved oxygen and organic content) and salinity (from fresh to hyper-saline salt lakes).

### *4.2 Dispersal ability*

Overall the ability of Gambusia to disperse is moderate to weak compared with most other Tasmanian freshwater fish species – many of which are migratory for some or all of their life history. Despite this, Gambusia has the ability to disperse widely within favourable habitats such as estuarine wetlands, large freshwater wetland complexes and slow flowing river drainage networks. Dispersal is significantly reduced or ceases at higher flow velocities (Congdon 1994), especially > 0.5 - 1 m/s, but the species is known to take advantage of marginal low velocity areas to disperse, even in higher flow environments. Gambusia has been widely observed to passively disperse downstream by flooding, and to take advantage of higher connectivity during and after flooding to disperse among lower velocity habitats. Dispersal tends to be greater for females. Larger females tend to disperse more frequently downstream, while males and juveniles show no directional preference during dispersal.

Its' ability to disperse coastally from one estuarine system to another is unknown, though its tolerance of high salinity suggests that this is possible.

### *4.3 Life history*

Gambusia has a high reproductive rate, focused in spring-summer, and bears live young. The reproductive cycle is regulated by a combination of photoperiod and temperature, with the windows of regulation falling well within the range of climatic conditions observed in Tasmania, with the possible exception of some highland lakes during cooler years.

Female Gambusia develop mature eggs in spring at mean temperatures above ca. 14 °C, and these finish maturing when mean temperature reach about 18 °C. Late in summer when the photoperiod is less than 12.5 hours long, mature egg development slows and eventually ceases (Koya and Kamiya 2000). In one reproductive season a female may produce several broods of embryos with brood size changing through the season.

Thus the species reproduces intensively and abundantly during spring – late summer.

### *4.4 Feeding requirements*

Gambusia's dietary requirements are broad, with a focus on smaller animal and detrital material; the predominant food items are zooplankton, small insects and insect larvae from the benthos and water column, and detritus material. The species is also carnivorous on their own young as well as larvae of other small fish. It also nips the fins of tadpoles and slower moving fish for food. Both of these feeding habits as well as the level of feeding activity ('aggression') are density-dependent, with a greater incidence of fin-nipping at higher Gambusia densities.

Gambusia is known to actively feed on eggs and larvae of a range of other fish species in Australia, as well as on eggs and tadpoles of several frog species.

## *4.5 Current distribution within Tasmania*

The current Tasmanian distribution is believed to be restricted to the immediate vicinity of the Tamar estuary and its estuarine wetlands. Details of the known distribution within the Tamar estuary are reported by Lynch (2008) and Scurr (2010, and pers. comm.).

The current belief that the distribution is restricted to the Tamar estuary is based largely on surveys conducted in 2000 to 2006, and an absence of any new, formally recorded reported sightings in recent years (though new anecdotal but unconfirmed observations have been reported). The original surveys were restricted to the immediate vicinity of the initial infestation zone, and were not accompanied by a broader ranging surveillance survey of possible candidate waterbodies (farm dams etc.) in the area.

The current control program is focused on control at a selected set of well-known sites within the immediate area of the estuary – largely based on high risk sites identified by Lynch (2008). No further systematic waterbody surveys have been conducted since the late 2000's, either within the known distribution in the estuary, further afield in the estuary or outside the estuary.

Public notifications to the IFS and others have revealed several other populations isolated to farm dams in southern Tasmania, the sources of which are unknown. These latter populations were eradicated by the IFS, though more may exist.

These notifications, the lack of recent survey work in the Tamar estuary and its vicinity, and the absence of any broader systematic surveillance of freshwater or estuarine fish populations in either the South Esk Basin or Tasmania generally, make it unclear whether Gambusia has a wider distribution than currently believed.

## *4.6 History*

The current distribution within the Tamar estuary is believed to be a direct result of reproduction and dispersal of individuals that escaped an initial single release site in 1992. There may of course have been further unreported illegal translocations or stocking events since that time, or even before, but the general view is that the spread of the infestation has been gradual and contained within the immediate area of the original infestation, despite the absence of recent more extensive survey data.

### *4.7 Suitability and vulnerability of habitats to infestation*

It is important to distinguish between habitats and assets (individual wetlands, streams etc.) which are vulnerable to the introduction of Gambusia from elsewhere though *translocation* or *dispersal*, and habitats which are subsequently vulnerable to Gambusia population *establishment* though successful survival and breeding.

#### *4.7.1 Highly vulnerable habitats*

Habitats that have higher vulnerability to Gambusia *dispersal or translocation* will include all riverine, wetland, lake and estuarine habitats which satisfy one or more of the following conditions:

- they are well connected to other suitable or already infested habitats, e.g. via a wetland drainage system, closely neighboring estuarine wetland habitats or part of a stream-wetland complex;
- they are at higher risk of stocking by humans (close to other established populations e.g. the Tamar estuary, or on readily accessible private land);
- they are owned or adjacent to land owned by private citizens who are unaware of the status of Gambusia, are motivated to stock waters to control mosquitos and can gain access to Gambusia individuals or infested habitats;
- they are regularly or intermittently stocked with other alien or native fish (trout, salmon or eels) sourced from infested or potentially infested waters – this situation is not believed to occur at present, but may become a significant issue if the infestation spreads widely.

Highly vulnerable habitats to Gambusia *establishment* will include all rivers, wetlands and estuarine habitats which:

- consist of predominantly still water, or of waters with current speeds < 0.3 m/s;
- attain temperatures of >14 degrees for the majority of the warmer months, and preferably contain habitat patches which sustain temperatures above 20 – 25 degrees;

- do not freeze for prolonged periods of the year;
- do not suffer from acute, high toxicity industrial or wastewater pollution.

Gambusia establishment may be further enhanced by the presence of dense aquatic plant growth, but is not dependent on its presence.

### 4.7.2 Less vulnerable habitats

Habitats of reduced vulnerability to Gambusia *dispersal or translocation* are those which:

- are upstream of long or steep stream sections which consist primarily of turbulent areas of flow which generally exceeds 0.3 to 0.5 m/s, and which are not readily accessed by humans;
- not readily accessed by humans, e.g. in remote areas and/or in formal reserves.

Habitats of reduced vulnerability to Gambusia *establishment* are those which:

- do not contain areas of still water, and/or consist primarily of steep, turbulent areas of flow which generally exceeds 0.3 to 0.5 m/s;
- suffer from acute toxic pollution.

## 4.8 Passive and active dispersal mechanisms

### 4.8.1 Human translocation

Active dispersal by humans, either through recognized governmental or corporate supported programs (e.g. in the USA) or by private citizens in the belief that Gambusia controls mosquito larval populations, has been the primary mode of dispersal of Gambusia globally for many decades (Macdonald and Zonkin 2008).

The establishment of Gambusia in Tasmania occurred by the deliberate transport and release of individuals (from Queensland) into a private farm dam adjacent to the Tamar estuary in the early 1990's.

Human translocation cannot be fully prevented, nor formally controlled other than by regulation. A strong public awareness and education program can be useful in developing an appropriate community attitude toward the species and human interactions with it. It should also be noted that raising community awareness also runs the risk of further raising awareness of the species for those parts of the community motivated, for various reasons, to translocate it further.

This phenomenon was observed during the Tasmanian IFS Cherax yabby farm dam eradication program in the late 1980's to early 1990's. Formal notification of landowners and raising of community awareness directly resulted in further local translocation of what was seen as a desirable species from already infested areas (followed by re-introduction into several dams from which the species had been eradicated).

Public awareness programs therefore need a carefully crafted message and sustained support. It is noted that at least one individual in the Tamar area has been identified who has been strongly motivated to conduct illegal Gambusia translocations.

Further human translocation of Gambusia within Tasmania is believed to have resulted in the establishment of populations at several farm dams in the south.

### *4.8.2 Natural dispersal*

Local dispersal by natural means – both active (swimming) and passive (relocation by flooding or strong currents) is well known for Gambusia both within habitats and between closely connected habitats in wetland, stream and estuarine environments. While rates of dispersal are generally described as low (with the exception of larger scale downstream dispersal by large flood events), they have a high probability of establishing new populations within catchments over the medium to longer term (years to decades).

The evidence for natural dispersal between disconnected or distant waterbodies by other natural vectors (birds etc.) is limited and generally speculative. The probability of this occurring should be regarded as low.

There is no published evidence of the species moving between estuaries along the coast. Tolerance of high salinities and recorded observations of natural dispersal within and along highly saline wetland environments, however, suggest this may be possible. There is empirical evidence for this mechanism of dispersal from one catchment to another for brown trout and atlantic salmon in Tasmania (IFS unpub. data and Annual Reports). This mechanism of Gambusia movement should be regarded as possible, though with a low probability (due to dispersal in coastal currents, weak swimming ability and predatory pressure).

**Table 2. Hazard criteria and their ratings for Gambusia invasion and impact in Tasmania.**

| Criterion | Criterion Feature | Description for Gambusia | Criterion Rating | Qualifiers |
|---|---|---|---|---|
| **Invasiveness** | | | | |
| | Habitat range | Very wide range of suitable aquatic habitats, including wetlands, rivers, lakes and lagoons, estuaries, saltmarshes; especially in lowland coastal, floodplain and agricultural areas. | Very High | |
| | Mesohabitat preferences | Broad habitat preferences with the exclusion of high velocity turbulent flow. | Low to Moderate | Steeper, higher velocity and turbulence streams |
| | | | High | Requirements cover most remaining habitats |
| | Temperature tolerance | Very broad temperature tolerance (15-35°C) and adaptation range and high temperature survival threshold (ca. 38°C). Tolerances cover temperature range of all Tasmanian waters; however, reproduction and growth cease below ca. 15°C. | Low to Moderate | Summer reproduction and/or growth likely to be limited or cease in highland lakes (> 900m) and some upland and western stream systems |
| | | | High to Very High | All lowland waterbodies, wetlands, estuaries and streams, especially in the north and east |
| | Salinity tolerance | Very broad salinity tolerance and adaptation range and high salinity survival threshold (ca. 60 ppt). | Very High | |
| | Water pH, colour etc | Broad range of pH, turbidity, water colour tolerance, tolerant of low dissolved oxygen levels (ca. 1 mg/l). | Low to Moderate | Acid drainage & industrially polluted streams |
| | | | Very High | All other habitats |

| | | | | |
|---|---|---|---|---|
| | Breeding ability | Spring-summer seasonal and prolific breeder. Timing and duration driven by water temperatures and photoperiod. Live bearing. No specific habitat/substrate requirements for breeding initiation or success. | High | Lowland habitats |
| | | | Low to Moderate | Higher elevation colder streams, wetland & lakes |
| **Dispersal** | | | | |
| | Natural means | Non-migratory species, weak swimming ability | Low to Moderate | |
| | Deliberate human means | Readily captured and transported. Seen as desirable by some community members. | High | |
| | Accidental human means | Commercial, recreational and government fish translocation activities a potential vector if source areas are infested. QA/QC programs required. | Low to Moderate | |
| **Competitive/Predatory ability** | | | | |
| | Within population | Cannibalism & competition frequently observed at high densities. However, not a significant regulator of population. | Low to Moderate | |
| | Between species: | | | |
| | Fish | Intense predation on fish eggs and larvae observed at moderate to high densities. Direct predation on juveniles of smaller native fish. Decline in native fish condition from fin nipping lesions and/or food competition. Gambusia is associated with decline of ca. nine Australian native fish species. | Moderate to High | Predation on eggs, juveniles and small adults, fin nipping & food competition at higher densities - for several species (see text) |

| | | | | |
|---|---|---|---|---|
| | | | Low | Open water, faster swimming and/or migratory species |
| | | | Very High | For most TSPA and EPBC listed Tasmanian freshwater fish species except Grayling |
| | Frogs | Intense predation on eggs and tadpoles (including fin nipping) observed at moderate to high densities. Gambusia is associated with the decline of between 10 and 15 mainland Australian frog species. | High | For most open water spawning species – 9 of the 10 Tasmanian frog species |
| | | | Low/Absent | For species with no free water dependence (e.g. Moss froglet) |
| | Invertebrates | Direct predation on smaller invertebrates (insects and crustaceans) in the water column and on bottom and plant surfaces. | Low | Open water faster swimming or larger/cryptic benthic species |
| | | | Moderate to High | Predation on zooplankton, some benthic invertebrates |
| | | | High | Potentially for some listed invertebrates |
| Algae | | Indirect effects due to zooplankton predation possible | Low | |
| Macrophytes | | No direct or indirect effects on non-algal plants | Low | |
| Other | | No direct or indirect effects on platypus, water rats or birds | Low | |

## 5. Application of hazard levels to CFEV aquatic asset GIS layers.

### *5.1 Hazard rating application*

Evaluation of the hazard criteria ratings for Gambusia invasion and establishment in differing habitat types resulted in the following conclusions:

Hazard ratings for *wetlands*, as well as for and *lakes* and *lagoons* ('waterbodies' in CFEV), of all salinities, are:

- Moderate to high for all assets at altitudes below 400 m – these assets are highly likely to have suitable temperatures for growth, oocyte development and reproduction and contain highly suitable marginal (shoreline), shallow open water, macrophyte and other associated habitat areas;
- Low to absent for all assets above 900m, where summer air and water daily and monthly maximum temperatures have a low probability of exceeding 19-20 deg C (BOM 2012, DPIPWE Water Branch unpub. data) – an approximate lower threshold for sustained active Gambusia reproduction;
- Moderate for all assets at intermediate elevations (400m to 900m) – where temperatures are intermittently above the Gambusia's minimum reproductive threshold.

Hazard ratings for infestation by Gambusia for *rivers* are:

- moderate to high for lowland rivers of low slopes (< 0.2%) – with potential for moderate to high densities in marginal and slow flowing and shallower habitats;
- low to moderate for slopes between 0.2 and 0.5% – with limited potential for moderate to high densities due to a limited availability of marginal and slow flowing and shallower habitats; and
- low to no hazard for river channels of slopes > 5% – with suitable marginal and slow flowing and shallower habitats being rare or absent.
- low to no risk for all 1$^{st}$ and 2$^{nd}$ order stream channels due to their marked intermittency of flow and frequent loss of wetted habitat during summer-autumn. Stream order (sensu Strahler 1957) denotes the position in the stream network, with 1$^{st}$ order streams being those mapped stream lines with no tributary inflows ('heads of catchment'), and 2$^{nd}$ order being those with only 1$^{st}$ order streams (typically 2 – 3 in number) as inflowing tributaries.
- Low to no risk for all stream channels > 900 m in elevation due to low spawning season temperature regimes. Note that this may also apply to

well shaded stream channels at lower elevations in deeply incised valleys in western Tasmania where temperature regimes remain cool in summer-autumn. The available data on stream temperatures does not yet allow these to be identified however.

The threshold of 0.2% is the channel slope above which habitat suitability for *Nannoperca australis* and juvenile *Perca fluviatilis* is deemed to be low (DPIW 2008) – species whose juveniles have a swimming ability and low tolerance to flow turbulence similar to Gambusia (Davies 2000; Ward et al. 2003).

Hazard and risk ratings for *estuaries* and *saltmarshes*, of all salinities, are:

- Moderate to high for all locations – these assets are highly likely to have suitable temperatures for growth, oocyte development and reproduction and contain highly suitable marginal (shoreline), shallow open water, macrophyte and other associated habitat areas. Some estuaries will have higher tidal flux and flow velocities than others, especially those in the north east, central north and north west, reducing the suitability of open water habitat areas. Others will have higher coastal energy environments, especially the west and south west coasts, reducing the suitability of shoreline habitats adjacent to coastal waters for Gambusia. However all estuaries are deemed to contain marginal and intertidal habitats suitable for Gambusia to become established once introduced. All saltmarsh habitats are highly suitable for Gambusia establishment, especially those internal to estuaries and sheltered embayments.

## 5.2 Results

The above rating rules were applied to the CFEV mapping units (river sections, polygons) for the wetland, waterbody, river, estuary and saltmarsh GIS layers – to produce maps of qualitative risk of Gambusia infestation. These are shown for the state in Figures 2 and 3 (and see Figures 4 to 17 in the Appendix for regional maps). No ratings were produced for other habitat types (karst systems, groundwater dependent ecosystems not listed above) due to lack of suitable data.

*Wetlands, lakes and lagoons:* All lowland wetlands, lagoons and lakes are rated as having moderate to high risk of Gambusia infestation (Figure 2). Figures 4 to 10 (see Appendix) show regions of the state at a larger scale. Those at upper elevations are rated as being at low to moderate risk due to lower spawning season temperature regimes, but are not rated as having no risk, as shallow water marginal habitats may still support Gambusia.

Extensive wetland areas in the north west in the Duck, Montague and Welcome catchments, the lower Boobyalla and Ringarooma catchments of the north east, north eastern wetlands of King Island and the eastern coast of Flinders Island and several south western catchments of the World Heritage Area (the Davey-Hardwood, Crossing, Giblin and Birchs Inlet catchments) are notable for their potential to develop into substantial well-connected areas of infestation.

In the Central Highlands (see Figure 10, Appendix), even if local extinction occurs following a series of cooler years, this may be followed by re-colonisation from wetland systems at lower elevation which still contain Gambusia, though rates may be slow. Dispersal through the Highlands and steeper western drainage systems will be strongly limited for higher elevation wetland systems by stream sections with steep slopes; however, the probability of active human translocation remains (as evidenced by repeated translocation of other exotic fish and invertebrate species in these areas in recent years).

*Rivers*: most lowland river catchment main channel systems across the state are rated as being at moderate to high risk of Gambusia infestation (Figure 3). Figures 11 to 17 (Appendix) show the regions of the state at a larger scale. Larger tributaries are rated as being at low to moderate risk, while all smaller tributaries are rated at low risk. There is potential for greater stream length in upper sections of wetter Tasmanian rivers to be at lower risk than these map attributions suggest (see note above).

Extensive lengths of river in the South Esk Basin, the far north west in the Duck, Montague and Welcome rivers, the Boobyalla and Ringarooma rivers of the north east, King Island and the eastern drainages of Flinders Island, and several western catchment rivers are notable for their potential to develop into substantial well-connected areas of infestation, depending on the extent of shallow marginal, riparian and floodplain associated habitat.

*Estuaries and saltmarshes:* all mapped estuarine and saltmarsh assets are rated as being at moderate to high risk (Figure 2, and 4 – 10 in Appendix).

Extensive wetland and saltmarsh complexes in the far north west in the Duck, Montague and Welcome catchments, the lower Boobyalla and Ringarooma catchments of the north east, and wetland complexes on Flinders and King Islands are notable for their potential to develop into substantial nodes of infestation, depending on the degree of drainage and conversion for agricultural development.

## *5.3 Summary*

It is apparent that there are extensive areas at risk of potential infestation of Gambusia in Tasmania across a wide range of habitat types and aquatic ecosystem assets. All river, wetland, waterbody and estuarine systems are likely to be suitable for establishment of Gambusia populations, once introduced through translocation or dispersal. Several major centres for infestation potentially exist – these include wetland and river channel complexes in several lowland catchments of the north east and north west, the larger Bass Strait Islands, and a number of wetland-rich lowland catchments in the south western region of the WHA. All estuaries and saltmarshes, especially in the north, east and south east, are likely to readily establish Gambusia populations along their margins and in intertidal and wetland habitats within them.

The rate at which Gambusia might disperse across the Tasmanian aquatic landscape will vary greatly and in the absence of human translocation will be slow (taking decades) between catchments. Local dispersal could be relatively fast within catchments in downstream directions following larger floods.

However, single human translocation events pose major risks by creating local nodes for dispersal within newly infested catchments, especially if a new translocation is to well-connected waterbodies (floodplain wetlands, large farm dams etc.). This was the case with the original translocation to a dam-channel system adjacent to the Tamar estuary.

Cooler temperatures and higher flow velocities will also limit both the rate of dispersal, the rate of establishment and the intensity of new infestations in the western and upland areas of the state. It is possible that the species will not become established in these areas. However, its broad temperature tolerance coupled with the potential for adaptation and projected longer term warming temperature trends mean that this is unlikely to be limiting in the long term.

There is almost no literature on the tolerance of Gambusia to very low salinities. Distributions of some invertebrates (most notably the shrimp Paratya) in the western areas of the Central Plateau are limited by very low ionic concentrations, and Plateau and western lake conductivities can fall as low as 10-20 microS/cm (compared to ca. 50,000 microS/cm in seawater). Low ionic stress may limit habitat suitability for Gambusia in many western lakes, though some of these lakes do contain Galaxiids. Further research is needed to determine low salinity tolerance thresholds for Gambusia.

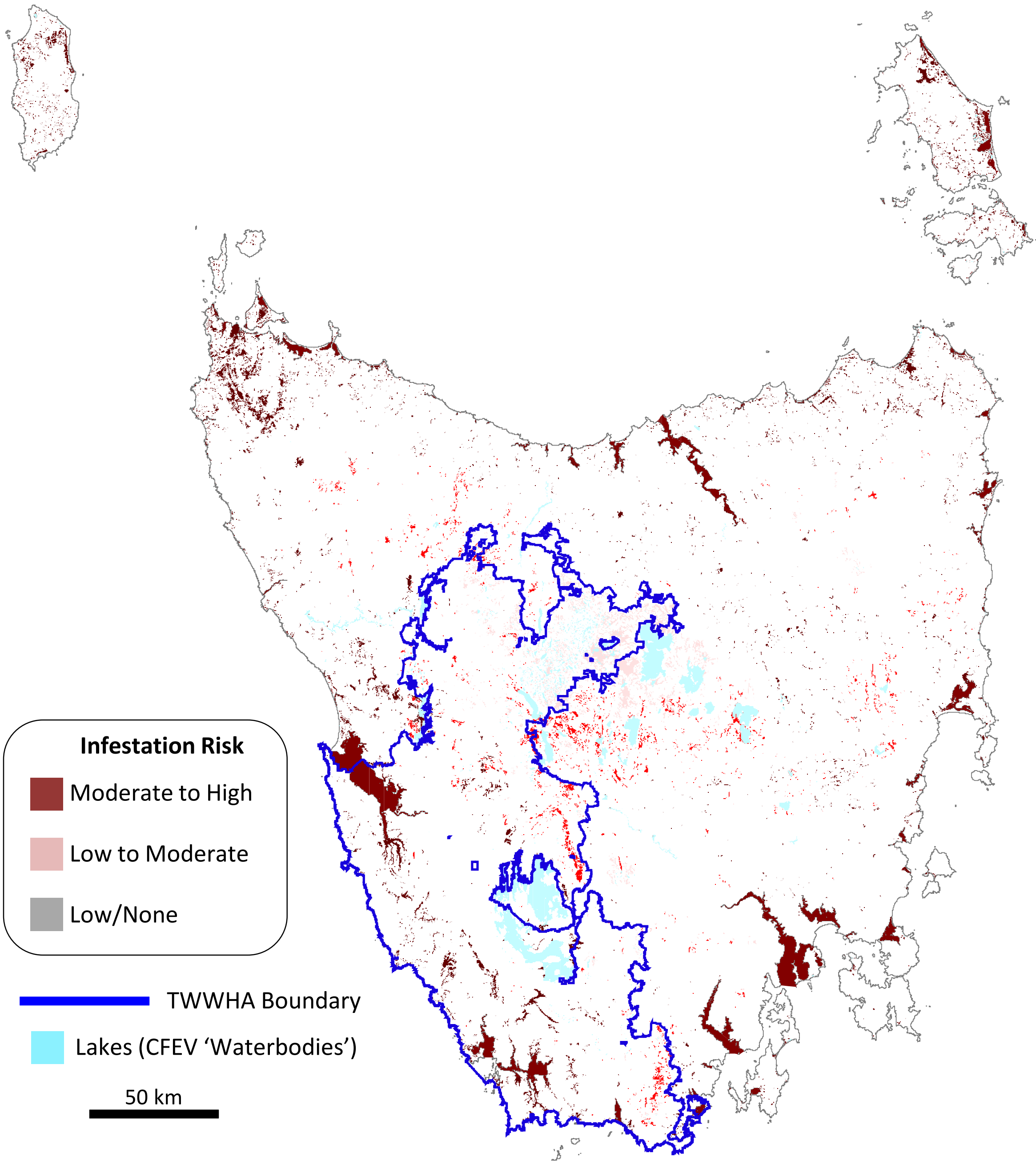


**Figure 2. State-wide distribution of wetlands and estuaries, showing varying levels of hazard of Gambusia infestation following dispersal or translocation. Location of World Heritage Area boundary and lakes (CFEV 'waterbodies') are shown for orientation.**

**Infestation Risk ratings:**

Moderate to High: moderate to high risk of permanent population establishment, generally in shallower and/or marginal habitats, potentially to high densities for much of the year;

Low to Moderate: low to moderate risk of permanent population establishment, generally in shallower and/or marginal habitats, and with localized low to moderate densities for part of the year;

Low/None: risk of permanent population establishment very low or absent, limited or only occasional occurrence at low densities and only when habitat conditions are highly favourable.

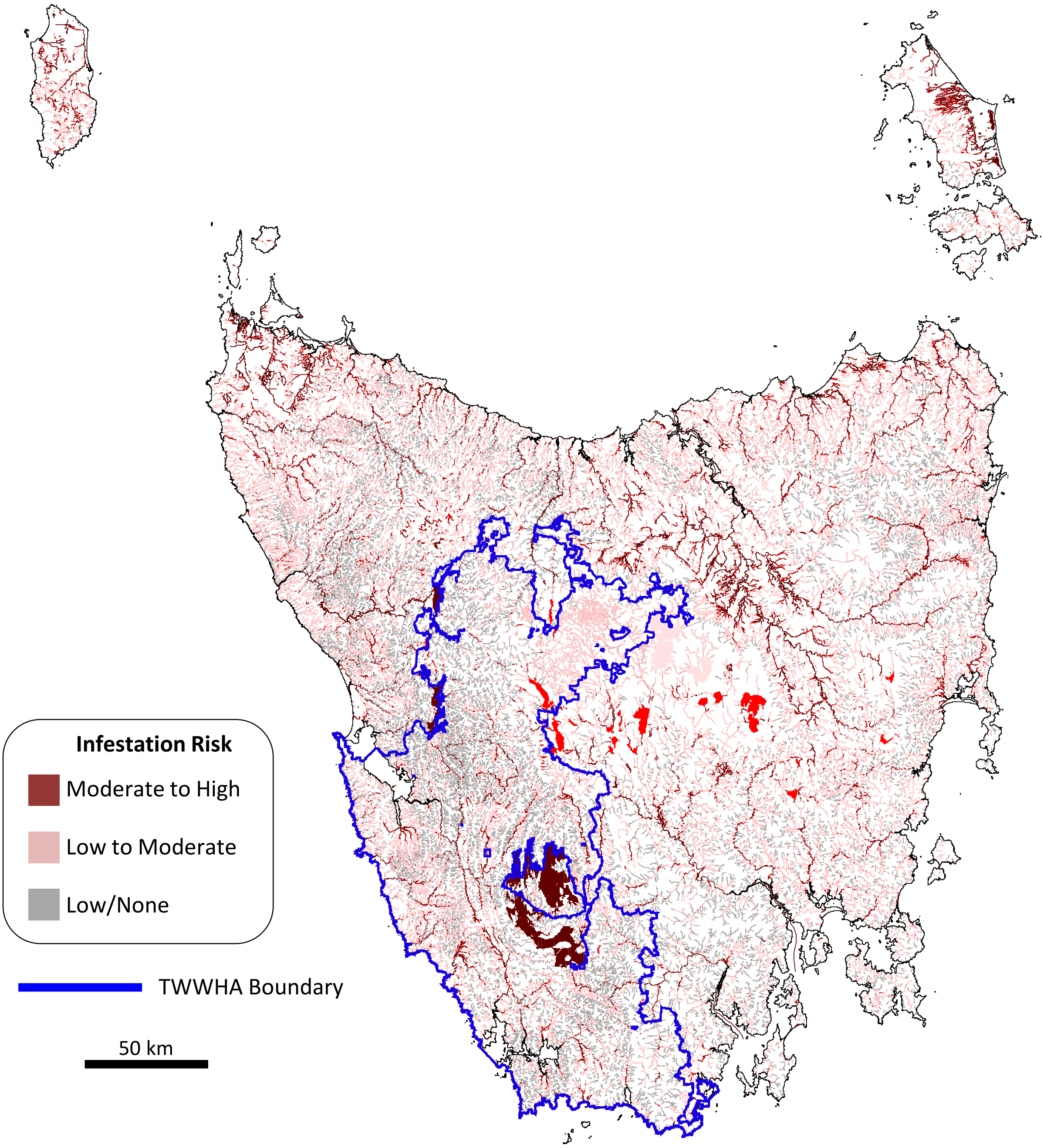


**Figure 3. State-wide distribution of lakes and lagoons (CFEV 'waterbodies') and rivers, showing varying levels of hazard of Gambusia infestation following dispersal or translocation. Location of World Heritage Area boundary is shown for orientation. River lines of Strahler stream order 1 and 2 (small headwater tributaries, all rated as having low/no hazard) are not shown, for clarity.**

**Infestation Risk ratings: See caption of Figure 2.**

## 6. Consequences of Gambusia infestation

### *6.1 Environmental consequences*

Given the extensive areas of potential infestation of Gambusia in Tasmania across a wide range of aquatic ecosystem types, assets and habitat types in Tasmania, it is important to be able to assess the likely impact of infestation on aquatic biodiversity and socioeconomic values. Table 3 identifies and rates the primary environmental and socioeconomic consequences of Gambusia infestation for Tasmanian environments.

Unfortunately, despite an extensive literature on Gambusia effects in the aquatic environment, most of the evidence is secondary in nature i.e. based on correlative field studies (Rowe et al. 2008). Tank and small mesocosm experiments have provided strong evidence for the mechanism of predatory and behavioural interactions between Gambusia and overseas and Australian native aquatic fauna, but may not reflect the magnitude of real world effects. Dietary and prey population status studies have also been conducted and demonstrated both direct and indirect effects of Gambusia on a range of aquatic species. Larger scale pre-post translocation studies of waterbodies on the scale of farm dams or small wetlands are still needed to provide a strong evidentiary basis for quantifying likely impacts.

Despite this lack of strong direct quantification of the level of biological impact, the weight of evidence indicates that the impacts on aquatic species can be substantial for several species of native fish and frogs. These impacts include reduction in population abundance, recruitment and condition, shifts in habitat use, and shifts in feeding behaviour. In addition, some trophic shifts have been observed in smaller, isolated water bodies leading to changes in algal abundance and associated turbidity.

There are several species of Tasmanian fish which are likely to be impacted substantially by the presence of locally high levels of Gambusia infestation. They include all the state and nationally listed Galaxiid and Paragalaxiid species, as well as the smaller wetland species such as Nannoperca fluviatilis (and Nannoperca Sp. Nov., a newly discovered species in the north east). Species occupying limited habitat area in shallow northern or coastal wetlands or lakes: Galaxiella pusilla, Galaxias parvus, Neochanna (formerly Galaxias) cleaveri and several lake dwelling species such as Galaxias auratus and Galaxias tanycephalus are particularly likely to be at risk, along with those with isolated small populations in small streams, such as Galaxias fontanus. These latter populations are already marginal due to the predatory impacts of redfin perch and brown trout. Addition of Gambusia, with its tendency to preferentially occupy warmer shallower waters, may add a significant additional pressure on these populations.

The majority of Tasmania's frog species are at risk of local to regional declines if substantial infestations of Gambusia become widespread. The threat posed to the conservation status of both the Growling Grass Frog, Litoria raniformis, and the Striped Marsh Frog, Limnodynastes peroni, is of particular concern.

### 6.2 Socioeconomic consequences

It is not currently possible to quantify the likely socioeconomic impact of widespread and/or locally intense Gambusia infestation – largely due to a lack of studies and relevant data. It is possible to propose some general conclusions however.

There are likely to be local impacts on shallow water lowland and coastal recreational fisheries for brown and rainbow trout, through effects on juvenile fish survival and food competition. Such fisheries tend to rely on stocking rather than natural recruitment. The effect of a Gambusia infestation on survival could be partially countered by stocking such waters with larger juvenile or early adult trout.

Large scale impacts on the recreational or commercial fisheries are unlikely, as Gambusia are unlikely to effectively target or impact on reproductive success, habitat quality or feeding requirements of trout or eels in larger waterbodies. The habitat requirements are unlikely to strongly overlap, predation by native fish and redfin perch in open water may be substantial, and survival and condition of larger fish is unlikely to be affected by the presence of Gambusia. There are no published studies which document the decline of populations or fisheries of trout or eels due to the presence of Gambusia, despite them co-existing within the same waterbodies in several regions of Europe and the USA.

Localised impacts on social amenity and aesthetic values could occur through:

- Changes in water quality due to predation by gambusia on zooplankton and the resulting enhanced phytoplankton density – affecting both water turbidity and/or colour. This type of 'top down' control of water quality is well known, and has been observed for some small waterbodies infested with Gambusia. It is likely to be restricted to smaller private or public water bodies such as smaller farm dams or storages in which Gambusia population densities are high enough to consistently drive down zooplankton density and which are sufficiently nutrient rich to maintain high phytoplankton production rates. It is highly unlikely in larger water bodies or those with even moderate water turnover times. Gambusia is also reported to enhance primary productivity through increasing allocthonous (internal) nutrient loads (Hargrave 2006). These effects are unlikely to be widespread in a Tasmanian context. Management costs for an affected waterbody may or may not be substantial, depending on whether ongoing water treatment is required, or whether Gambusia eradication is possible.

- Perceptions related to Gambusia presence in waters of public amenity, high visibility or in conservation areas. This may lead to a general decline in public perception of the integrity of Tasmanian aquatic ecosystems. This is difficult to quantify, as there has already been a broad acceptance by the community of high levels of infestation by exotic fish species, notably redfin perch, trout and tench, in many waters across the state.

Increased costs associated with management of other species are likely to occur in the following cases:

- Mitigation costs: Costs may be incurred to mitigate impacts of Gambusia on the conservation status of listed threatened native fish and frog species where Gambusia is found to be a significant threatening process. This might include construction or enhancement of barriers to dispersal, translocation, or additional intensive measures to control local Gambusia infestations.
- Fish translocation costs: Additional costs are already occurring due to the need for additional quality assurance actions in elver transfers from the Trevallyn tailrace – in part due to concerns over the potential for Gambusia translocation. The tailrace is the principal source of elvers of Anguilla australis for the Tasmanian commercial eel fishery (with 12 commercial operators) and also for a substantial part of the Victorian eel fishery. Most of these elvers are translocated to a range of waterbodies across the state for the purpose of ongrowing and later harvest, processing and sale. Concerns over by-catch and inadvertent translocation of Gambusia and other species during this process have prompted trialing and introduction of live grading procedures. These are now centrally managed at a commercial facility at Bagdad, to and from which elver stock must be transported. Additional costs may be incurred if this process requires further intensification, and also if commercial or

government hatcheries which provide brown and rainbow trout stock for stocking private and public waters become infested with Gambusia. Additional screening, grading, and other quality control measures may be required to prevent trout stocking operations becoming a translocation pathway.

Additional costs will also be incurred through an increased research and management effort focused on Gambusia. The latter is likely to include increased allocation of funding and resources for control and eradication activities, as well as communication and education – in order to restrict or reduce the rate and extent of Gambusia dispersal and infestation.

It is not possible to quantify any of the above costs at present.

**Table 3. Consequence criteria and their ratings for possible environmental, social & economic impacts of Gambusia invasion in Tasmania.**

| Criterion | Criterion Feature | Description | Criterion Rating | Qualifiers |
|---|---|---|---|---|
| **Socio-economic** | | | | |
| | Recreational fishery decline | There is limited overlap in the habitat requirements for brown trout spawning and juveniles and for Gambusia. Predation pressure on eggs, larvae and juveniles is likely not to exist. There may however be competitive pressure for food resources and the potential for fin nipping of juvenile trout stocked into shallower, enclosed lowland waters. This may have a moderate impact on the quality of these trout fisheries. | Moderate | For enclosed, lowland, shallow trout fisheries |
| | | | Low | For all other fisheries |
| | Aesthetic value decline | Some waters may experience enhanced algal growth if heavily infested with Gambusia. There may also be a negative aesthetic perception for waters with high, visible densities of Gambusia. | Low to Moderate | Possible in smaller, shallow enclosed waterbodies where algal densities increase due to zooplankton predation |
| | | | Moderate | In publically visible habitats promoted or perceived as pristine |

| | | | | |
|---|---|---|---|---|
| | Water supply utility decline | Possible for smaller, shallow enclosed waterbodies where algal densities increase due to zooplankton predation by Gambusia | Low | |
| | Management costs : | | | |
| | Implementation costs | If implementation costs are excessive, the program may not be applied consistently enough over the long term to be effective. | High | |
| | Control effectiveness | Risks are high in the long term if control methods are weak or ineffectively applied. | High | |
| | Control duration | Long term investment required | High | |
| | Impact management costs | Intensification of threatened species management may be required for invaded habitats of listed galaxiids. | Low to Moderate | |
| | | | | |
| **Environmental** | | | | |
| | Aquatic biodiversity decline | Decline in some vulnerable species may be severe (see Tables 1 and 2) in selected habitats – especially isolated, shallow water wetlands, lagoons and lakes and marginal wetlands and backwaters of estuaries and slower flowing rivers. | High | For shallow, lowland coastal, estuarine and floodplain wetlands, lagoons and farm dams. Depends on habitat complexity and flooding susceptibility. |

| | | | | |
|---|---|---|---|---|
| | | Overall biodiversity declines may be substantial in small, enclose and disconnected/ isolated lowland waterbodies with little vegetative cover. | | |
| | | | Moderate to High | For smaller, disconnected coastal and floodplain stream systems with shallow gradients and fine substrates |
| | | | Low | Most other habitats will experience individual species impacts but unlikely to experience major biodiversity declines |
| | Aquatic Species/community impacts | See notes above in Table 2 under Competitive/Predatory ability for species. Impacts greatest on native fish community and benthic and water column invertebrates. | Moderate to High | For species as listed in Table 2 under Competitive/Predatory ability (also in text) |
| | | | Low | All other species |
| | Ecosystem function changes | Possible in smaller, shallow enclosed waterbodies where algal densities increase due to zooplankton predation – may cause macrophyte decline and transient 'state' changes. | Low to Moderate | |

| | | | |
|---|---|---|---|
| Disease vectors | Bacterial, fungal and trematode disease agents are known to impact wild and captive Gambusia populations. Mosquito fish are potential hosts of helminth parasites, which can be transmitted to native fishes. However no specific disease vector risk has been associated with Gambusia in Australia. | Low | Limited evidence |

## 7. Overall conclusions of risk assessment

The hazard rating for Gambusia infestation of most Tasmanian aquatic ecosystem types and assets is generally high. Some locations have lower suitability for Gambusia due to temperature and velocity constraints. Dispersal may be slowed or restricted due to instream barriers to movement and by the limited potential for dispersal across catchment boundaries (noting that coastal dispersal is not well understood). This does not alter the long term prognosis that most aquatic habitats in Tasmania may ultimately contain and sustain Gambusia populations.

Infestations will tend to be more substantial and widespread in lowland and coastal, shallow wetland, lagoon, farm dam, estuary and saltmarsh habitats. However marginal habitats in many less suitable stream, wetland and waterbody assets are still highly likely to sustain permanent or periodically re-establishing populations if introduction has occurred. While cooler temperatures, especially above 900 m are likely to severely restrict reproduction, warmer summers coupled with gradual climatic warming may still allow at least transient recruitment in shallow habitats. Predation by both native fish species and other alien species (trout, redfin perch) will occur but is unlikely to provide substantive control of abundance in any water.

Unintentional or intentional human translocation will remain the single most likely route of cross-catchment movement and introduction to new aquatic assets. Education, training and the maintenance of translocation protocols will reduce the frequency at which translocations will occur. Despite this, it is likely to continue to be conducted by members of the general community, as well as by government and commercial operators – the latter due to poor quality assurance and control practices in recreational and commercial fish translocation operations.

Overall, the risk of infestation is high statewide in the medium to long term, and this presents a high and spatially extensive hazard to the state's aquatic ecosystems.

The consequences of Gambusia infestation are likely to be quite variable depending on the nature of the habitat and the presence of vulnerable species. Consequences of severe infestations for nearly all frog species are likely to be severe, with local decline or event population extinctions being highly likely. Consequences for fish species are more variable, and will be limited for larger more mobile species which occupy faster flowing environments or with a wider range of habitat preferences. All listed Galaxiid and Paragalaxiid species are likely to be vulnerable to Gambusia predation and competition – for these species, as well as several other shallower water dependent species (e.g. Nannoperca, Retropinna) the potential for local population reductions or even extinction is substantial. Similarly, overall impacts on aquatic ecosystem benthic and water column invertebrate communities may be severe in highly infested shallower waters – and may possibly affect some listed species. Other consequences (water quality, socioeconomic impacts) are likely to be only locally and occasionally significant.

The overall combination of high and widespread infestation potential and locally intense consequences leads to a high overall risk from Gambusia to aquatic ecosystem biodiversity, frog community conservation status and the conservation status of up to 7 native endemic fish species. Risks to socioeconomic values are likely to be low to moderate, but may occasionally be locally high.

## 8. Commentary on Management

A number of reports and review documents relating to the Tamar Gambusia control program were provided for this review, including various program internal reports and reports by Pitman et al. (2011), Maynard et al. (2008), the thesis and risk assessment protocol by Lynch (2008) and the Control Strategy (Scurr 2010). Interviews were also held with a number of key players in the program and relevant government agencies with regard to the history of infestation in the Tamar and beyond, management activities and responsibilities, and comments on the current program and its needs.

With the current techniques available, eradication of Gambusia from Tasmania is now considered highly unlikely to be successful and to require too intense an investment in resources, with very limited chances of success. The current locus of infestation in the Tamar estuary consists of a dispersed set of intertidal and brackish to freshwater wetland and channel complexes. These habitats are highly internally connected and connected to the main body of the estuary, and generally have dense stands of emergent and submerged aquatic vegetation growing on soft sediments. Several are also connected to inflowing tributaries.

Complete eradication by physical means (netting, trapping, exclusion, draining) or poisoning is essentially impossible in this environment. Significant control of the entire population of such wetlands is also not feasible without a substantial and sustained investment in effort which would need to continue in perpetuity. The investment to date has been largely limited to control trials with differing methods and intensities of capture (e.g. trapping) and to local control at locations readily accessible to the public.

This report does not review the relative efficacy of these differing trapping methods and control approaches; the former are the subject of a report by Maynard et al. (2008), a draft report by Pitman et al. (2011) and a Master's thesis due for completion in late 2012. Pitman et al. (2011) report a decline in catch per unit effort (CPUE) over all three Tamar estuary trapping sites combined (Tranquility Gardens, Tamar Island Wetland Reserve and Landfall) between 2008 and 2010. However a fuller analysis is required to demonstrate that this decline is quantitatively linked to trapping effort, and should ideally include data from infested sites with no or minimal Gambusia harvesting, as well as measures of trapping effort.

However, it is apparent that the current trapping program:

- can result in at least transient declines in Gambusia abundance at intensively fished locations, though follow up with longer-term trapping would be required to maintain depressed abundances.

- can be used to reduce numbers in areas which allow ready access to the species for the public, though again the program needs to be sustained for the long term for this to remain an effective strategy.
- could, provided the above are effective, be used to reduce the likelihood of the species' spread, if accompanied by an effective communication and education program coupled with the existing spot eradication efforts conducted by the IFS.
- Can, when combined with other approaches (draining, poisoning), be used to facilitate eradication in isolated and disconnected environments such as farm dams.

The primary aim of the existing program has been to control the further spread of the species beyond the Tamar estuary (Scurr 2010) by reducing abundance especially at publically accessible locations. Initially conceived as an eradication program, it has progressed through local control trials using a range of trapping and netting techniques, construction of barriers and draining and poisoning of habitat (in conjunction with the IFS), to the current focus on control only around several locations which are readily accessed by the public. Thus the primary active focus is on:

- Control of Gambusia populations in public access areas to reduce the potential for translocation;
- Education through a combination of a volunteer network, public displays and presentations, and school presentations and activities.

The program is now run under a structured Control Strategy (2010), with activities whose focus is limited to control at sites within the Tamar valley, and associated awareness and community engagement actions.

In addition to the Tamar-focused program, the Inland Fisheries Service conducts population eradications, generally by rotenone poisoning, when notified of new infestation locations. There have been several of eradications in farm dams in the Tamar area, and in the south of Tasmania. This relies on almost solely on public notification of infestations, as IFS does not conduct a broad surveillance program for the detection of alien fish species.

Noteable issues relating to the current management of Gambusia in the Tamar and at the state level are:

- The need for a higher level of resourcing by NRM and/or state government (including the IFS) – the lack of a consistent funding source for management of Gambusia is leading to considerable uncertainty in the continuity of funding and morale of the program participants;

- The vulnerability of the program to any changes in the currently high level of personal commitment of the program participants at the ‘coal face’, noteably Grant Scurr and the volunteers;
- The need for a defined, formal work plan with clear short-term objectives and supervision – this is lacking despite the presence of the Strategic Plan and the Gambusia Working Group;
- More consistent engagement is required by IFS beyond attending Gambusia Working Group meetings – e.g. in taking a lead role in supervision of daily program activities;
- The need for clarity around the role of DPIPWE’s Biosecurity Branch in management and funding of the Gambusia infestation – a role which should be actively increased now that alien fish are included in the national Australian Pest Animal Strategy (NRMMC 2007).

The management of the Gambusia infestation threat is complex. Despite this, the program participants and relevant government agencies have evolved a reasonably logical overall approach:

- Control of populations around areas of ready public access in order to minimize translocation risks from the Tamar estuary and environs (by the program and IFS);
- Public education to raise awareness of the threat posed by Gambusia and to discourage translocation and raise the likelihood of public notifications of new infestations (by the program);
- Focused eradication of new infestations in new locations outside the Tamar estuary (by IFS) – effective in isolated habitats (e.g. farm dams) but probably less so if new infestations occur in well-connected and more complex habitats.
- Research into control methods – with a focus on trapping techniques.

This represents an overall policy of containment and education, coupled with eradication of new outbreaks, in a loose partnership between NRM North and Tamar (the program) and IFS, and with some researcher engagement.

This overall approach is logical and should be sustained. Both the approach and the current effort are commendable given the current status of the infestation, but are limited by a lack of resourcing. Further improvements are recommended as follows:

*Monitoring:* A regular periodic survey is required to ascertain the status and extent of infestation within the Tamar estuary and its tributaries. A survey should be conducted on a 5 yearly basis, using a standardized level of trapping effort and in the same season. The survey should cover the entire length of the Tamar estuary including the lower North Esk (tidal and freshwater), the Cut and the Trevallyn tailrace and extending to George Town. It should include both estuarine wetlands and stream channels and wetlands connected to the estuary. It should include all candidate sites – both high and low risk as defined using the protocol of Lynch (2008) – and a sample of connected sites within the immediate estuarine catchment (stream channels/farm dams/wetlands). The purpose is to understand both the extent and rate of spread of infestation within the estuary and its immediate catchment, and any substantive changes in population density. The survey should be conducted under the direction of IFS, as the state body responsible under legislation, in partnership with the program. It should follow a defined protocol, not rely solely on volunteer or student assistance, and report formally, and lodge data with a dedicated program database.

All other monitoring, control and eradication data should be collected systematically and lodged to the same database. All trap and control data should be recorded consistently, and should follow the data recording recommendations made by Pitman et al. (2011). Trapping effort and methods should be consistent so that abundance trends can be analysed statistically.

Clearer demonstration of the efficacy of control efforts should also be provided through ongoing analysis of consistently collected data.

*Education/Communication:* The current education and communication effort should be sustained and expanded to include the general community within the South Esk Basin and ideally state-wide (especially focusing on the angling community). Reporting of new infestations should be encouraged and where possible facilitated.

*Control efforts:* The current control efforts within the Tamar estuary should be sustained, and made more systematic. Efforts should focus on reducing contact between the community and Gambusia at the vulnerable sites that have already been identified. This should include restricting human access to vulnerable locations as well as reducing Gambusia numbers. The Gambusia Working Group should facilitate requests to establish low visual impact fencing at selected locations (e.g. the Tamar Wetland car park), and other means of reducing habitat suitability of accessible shorelines (e.g. vegetation of shoreline areas as proposed by Grant Scurr).

*Eradication:* IFS should continue its policy of eradication of newly detected populations. Such operations include follow-up surveys of the infested waterbodies, as well as local community liaison and surveys of neighbouring properties with the aim of detecting further infestations.

*Research:* a focused research program should be established by the Gambusia Working Group and funding sought for specific, well designed and formally approved and reviewed projects – where necessary in partnership with the University of Tasmania, the Australian Maritime College and CSIRO. Key research areas should include (among others): well-designed dam/wetland translocation and impact assessment experiments, development of genetic control methods (Trojan Y/Daughterless Gambusia strategies), assessments of low salinity tolerance thresholds and adaptation, and low temperature thermal adaptation. Research should be conducted as an activity distinct from the control and education activities. In the past program activities have tended to mix all three activities.

*Resourcing:* the program needs to be placed on a firmer and more substantial funding base. Current efforts to seek funding via the NRM/CFOC routes should be sustained. However, a joint arrangement and proposal should be developed between IFS, DPIPWE (both the RMC and Biosecurity Branches) to seek both state and federal funding under the banner of biosecurity threats and impacts of alien fish on aquatic biodiversity.

*Partnerships:* The Gambusia Working Group arrangement cannot provide for more ‘hands on’ management of the program, either as it stands or if more resources become available. A formal partnership arrangement between either IFS or DPIPWE and the state’s NRM regions (starting with NRM North and Tamar) should be established so that program employees routinely report to, and arrange work schedules with, a dedicated manager with aquatic biodiversity/fishery expertise (who in turn liaises with and reports to the Gambusia Working Group).

## 9. General Conclusions

This risk assessment indicates that Gambusia holbrooki is highly invasive. If uncontrolled, infestation will spread across the state, by both 'natural' dispersal and human translocation. Gambusia infestation poses a high risk to aquatic ecosystem diversity and in particular to the conservation status and survival of several native fish and most frog species across the state.

Those locations at greatest risk are all lowland and coastal wetlands, lagoons, rivers as well as estuaries and saltmarshes. Risk in the short to medium term is greatest in the north, east and southeast, though invasion across all regions in these habitats is probably inevitable in the absence of control. Steeper and higher elevation habitats are at lower risk of sustained and intense Gambusia infestation but are not immune to introduction and establishment, especially as the climate warms.

Consequences are likely to be severe for native fish and frogs in the habitats at greatest risk, but will generally be much lower in ecosystem assets and habitats in other areas.

This risk assessment is necessarily qualitative, due to the lack of several key pieces of information, and the inherent uncertainty around the rate of spread and intensity of infestation is substantial. A higher degree of certainty applies to the assessment of the ultimate spread of infestation (in the absence of effective genetically-based control). There is considerable uncertainty about the intensity of impact, which is likely to be both variable in space and time.

The current state of knowledge around the nature and intensity of impact on aquatic environments and species in Tasmania is weak and requires dedicated research. Lower temperature and salinity tolerances and adaptation also require further investigation to fully understand the potential for spread to sub-optimal habitats in the west and at higher elevations. Research is needed into possible genetic methods of control – particularly combinations of Trojan Y and Daughterless fish approaches.

The current control program should continue, with substantially greater resourcing and funding security, should be more closely managed, should be the subject of partnerships between government agencies and between government and NRM Tasmania, and should be supported by targeted well designed and peer-reviewed research.

The management of the Gambusia infestation is necessarily a Tasmanian state responsibility, with IFS being the lead agency under Inland Fisheries legislation; though biodiversity, threatened species and biosecurity implications require the active engagement of DPIPWE in Gambusia threat management. So, while the current focus is on the Tamar valley and estuary, and the program is appropriately managed via NRM North and Tamar NRM, a broader state-wide strategy is required, involving active state agency participation and partnerships. This should be developed soon, as the larger scale spread of Gambusia infestation in Tasmania is currently almost inevitable. Great Britain, Canada and the European Union are developing generic emergency response plans applicable to incursions of alien freshwater fish. A state-level plan is therefore strongly recommended, that builds on the experience of the Tamar control program, and is the basis for further funding applications and coordinated management.

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## Appendix 1. Regional Tasmanian maps of Gambusia infestation hazard

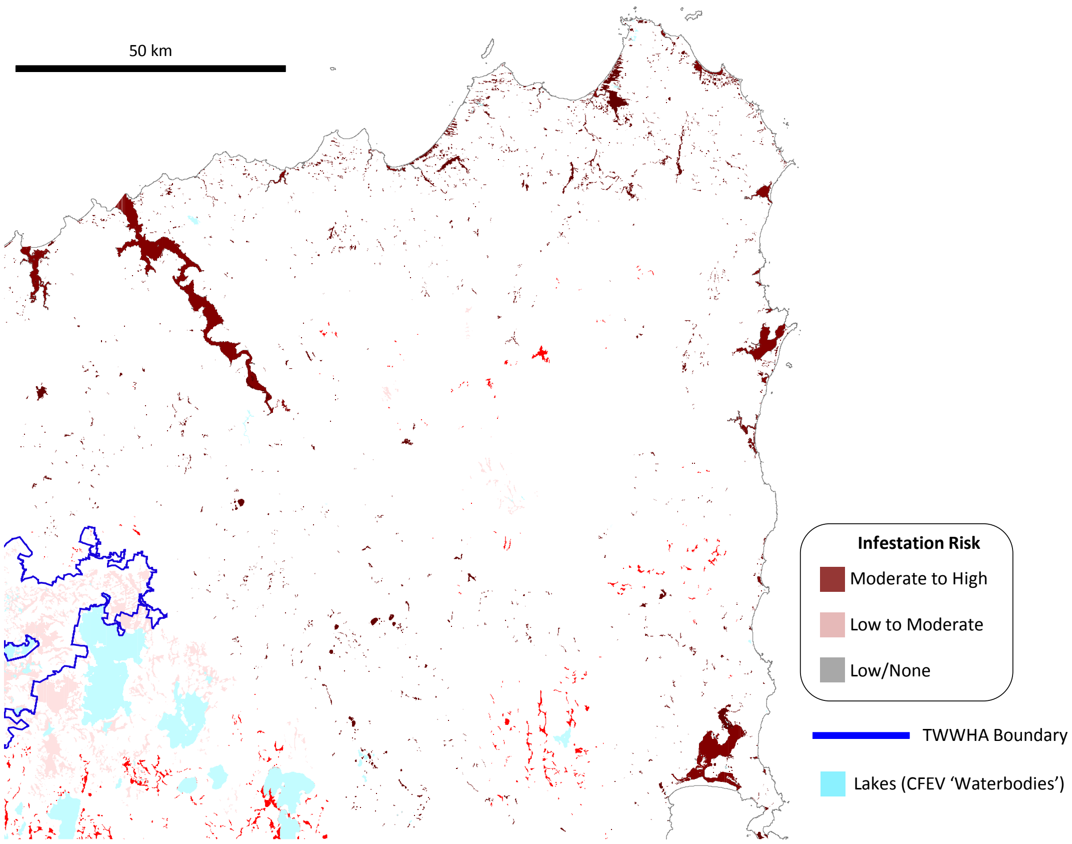


**Figure 4. Distribution of wetlands and estuaries in North East Tasmania, showing varying levels of hazard of Gambusia infestation following dispersal or translocation. Location of World Heritage Area boundary and lakes (CFEV 'waterbodies') shown for orientation.**

**Infestation Risk ratings: See caption of Figure 2.**

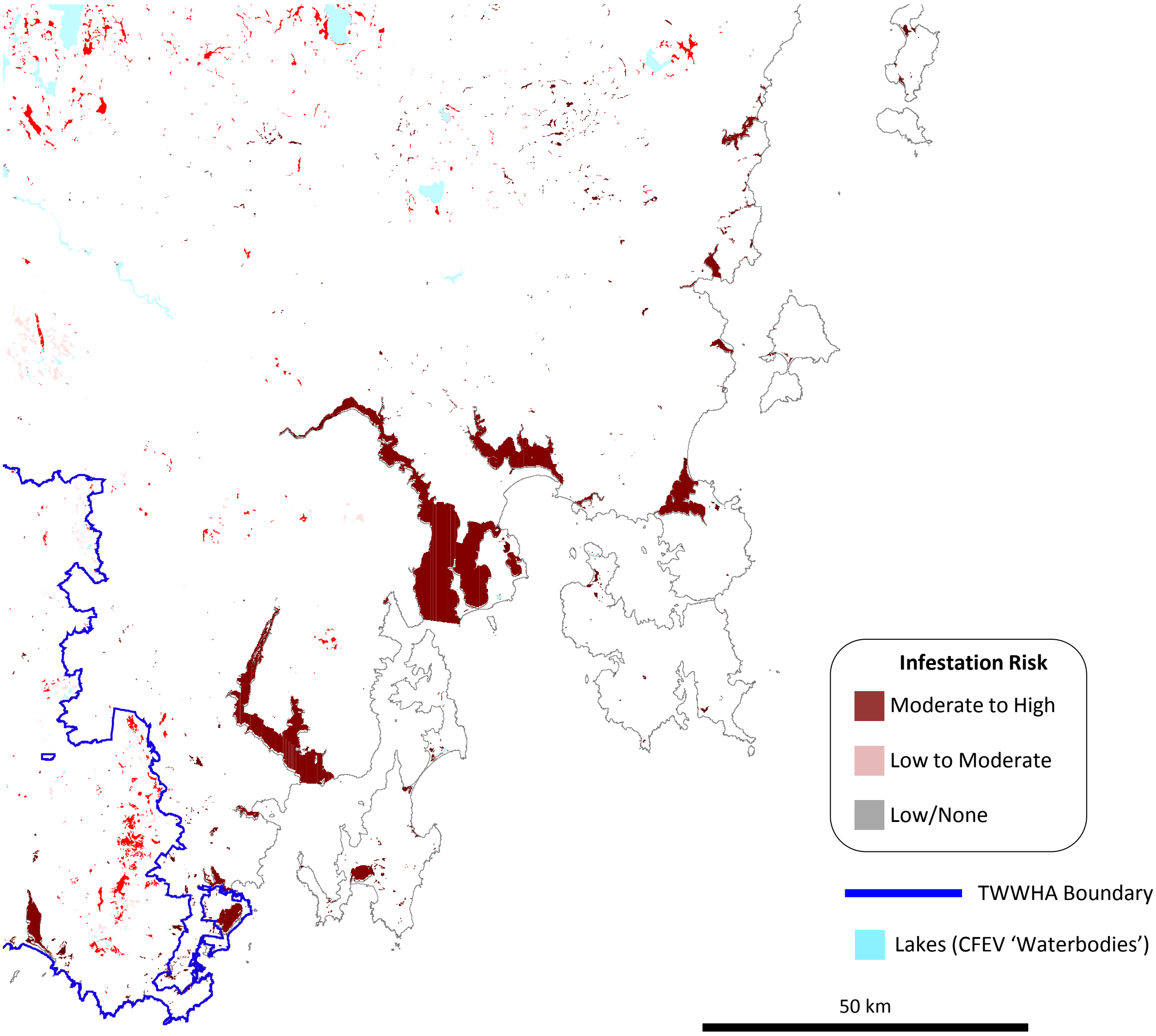


**Figure 5. Distribution of wetlands and estuaries in South East Tasmania, showing varying levels of hazard of Gambusia infestation following dispersal or translocation. Location of World Heritage Area boundary and lakes (CFEV 'waterbodies') shown for orientation.**

**Infestation Risk ratings: See caption of Figure 2.**

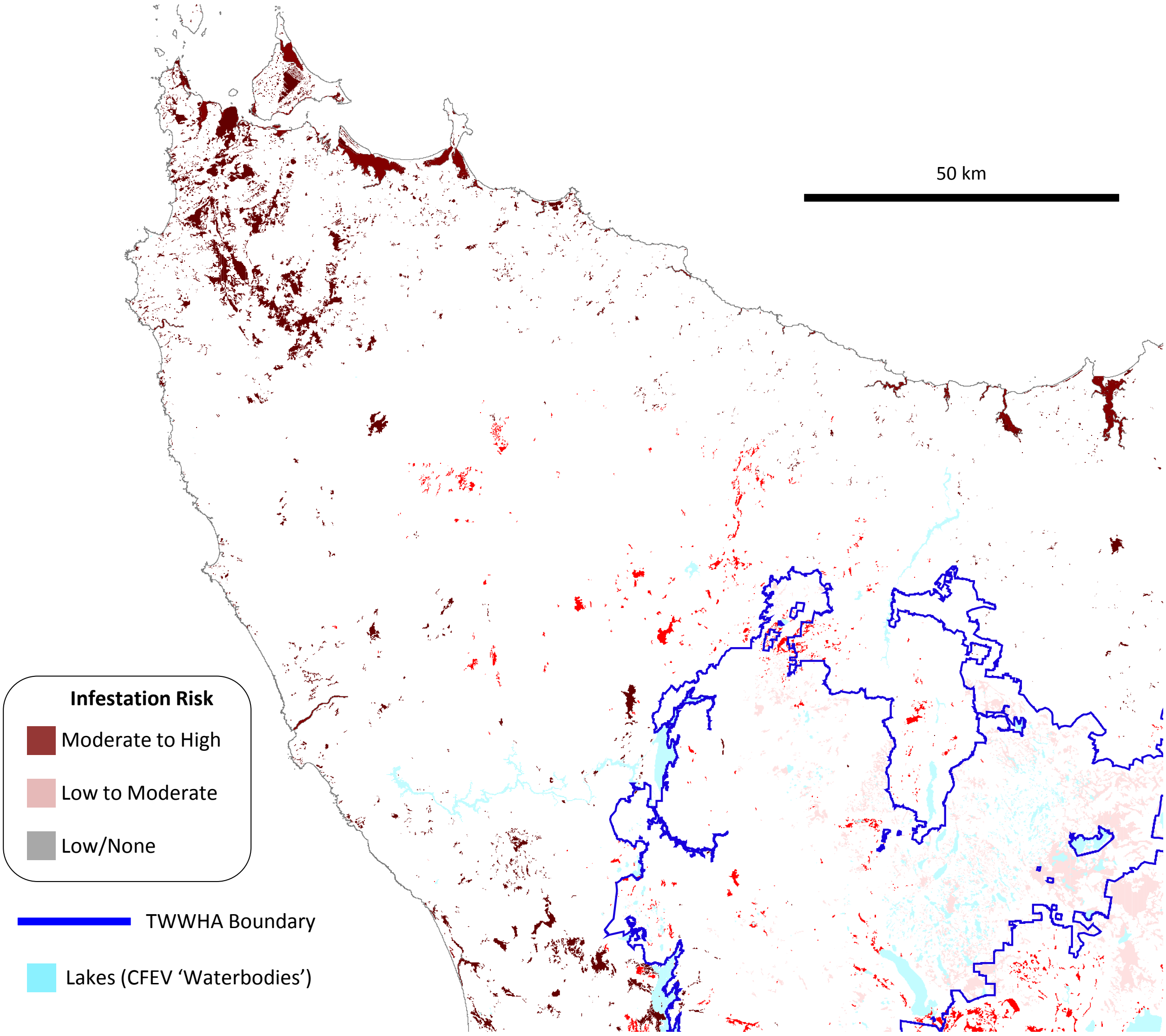


**Figure 6. Distribution of wetlands and estuaries in North West Tasmania, showing varying levels of hazard of Gambusia infestation following dispersal or translocation. Location of World Heritage Area boundary and lakes (CFEV 'waterbodies') shown for orientation.**

**Infestation Risk ratings: See caption of Figure 2.**

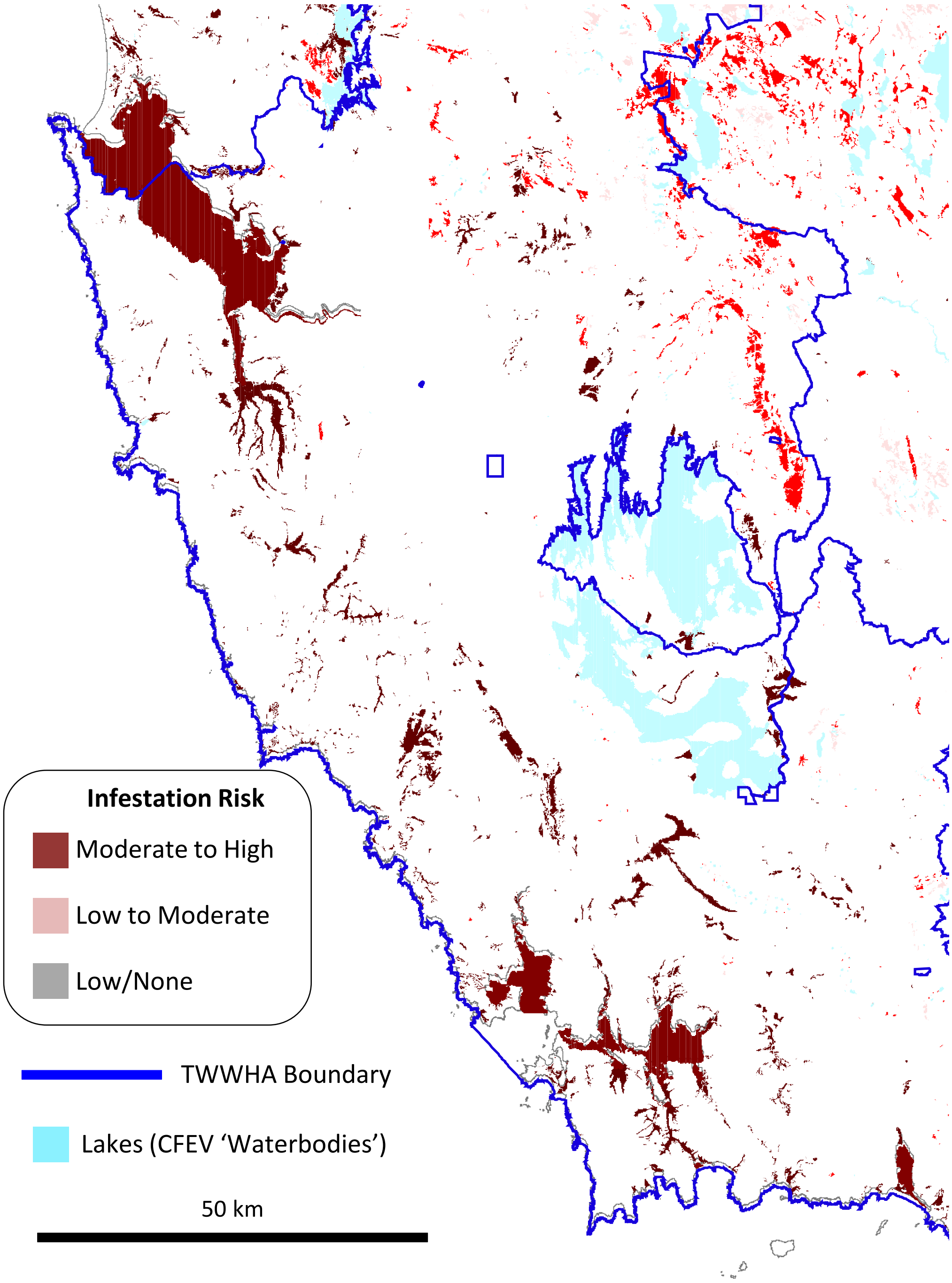


**Figure 7. Distribution of wetlands and estuaries in South West Tasmania, showing varying levels of hazard of Gambusia infestation following dispersal or translocation. Location of World Heritage Area boundary and lakes (CFEV 'waterbodies') shown for orientation.**

**Infestation Risk ratings: See caption of Figure 2.**

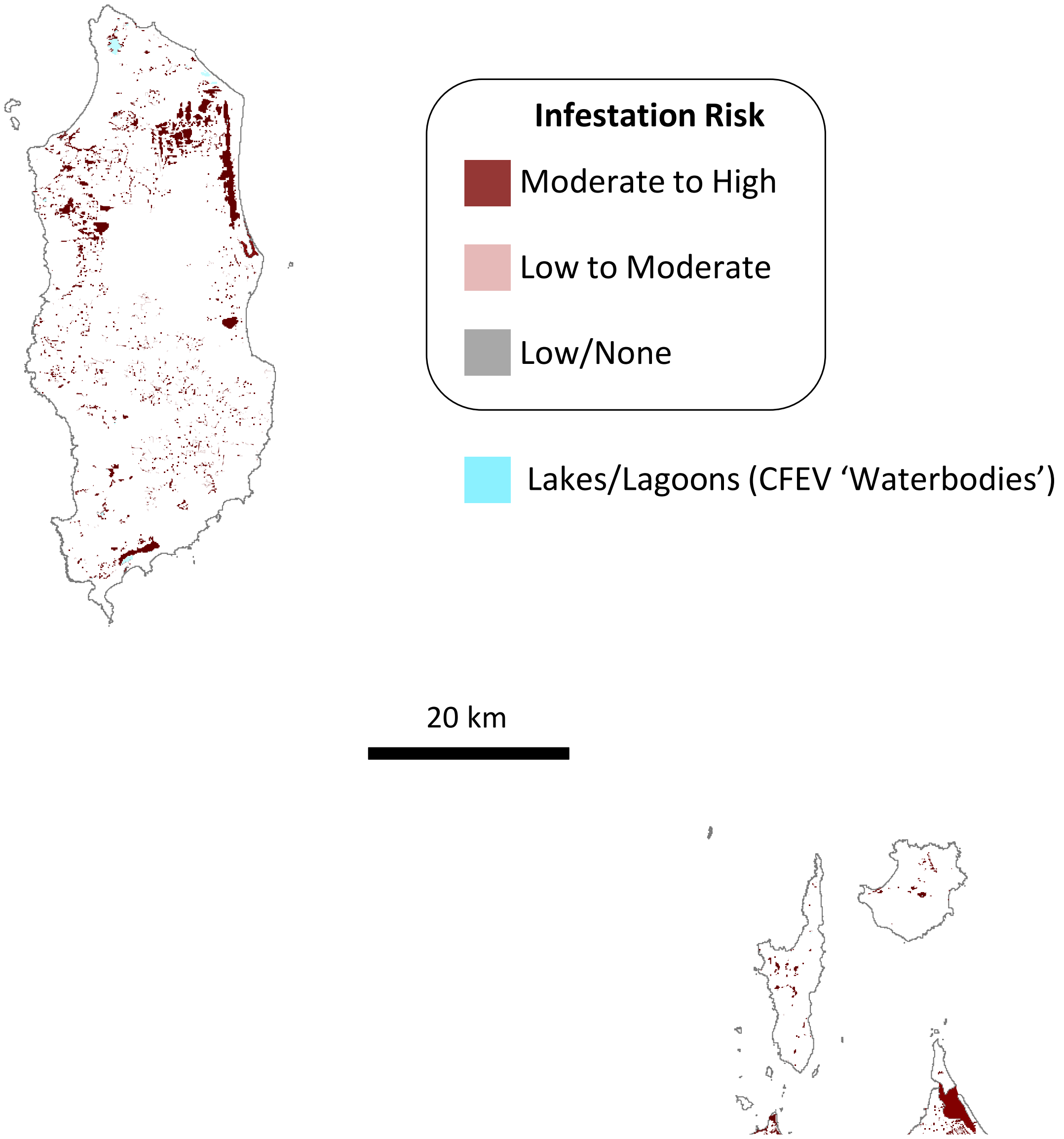


**Figure 8. Distribution of wetlands and estuaries on King, Hunter and Three Hummock Islands, showing varying levels of hazard of Gambusia infestation following dispersal or translocation. Location of lakes and lagoons (CFEV 'waterbodies') shown for orientation.**

**Infestation Risk ratings: See caption of Figure 2.**

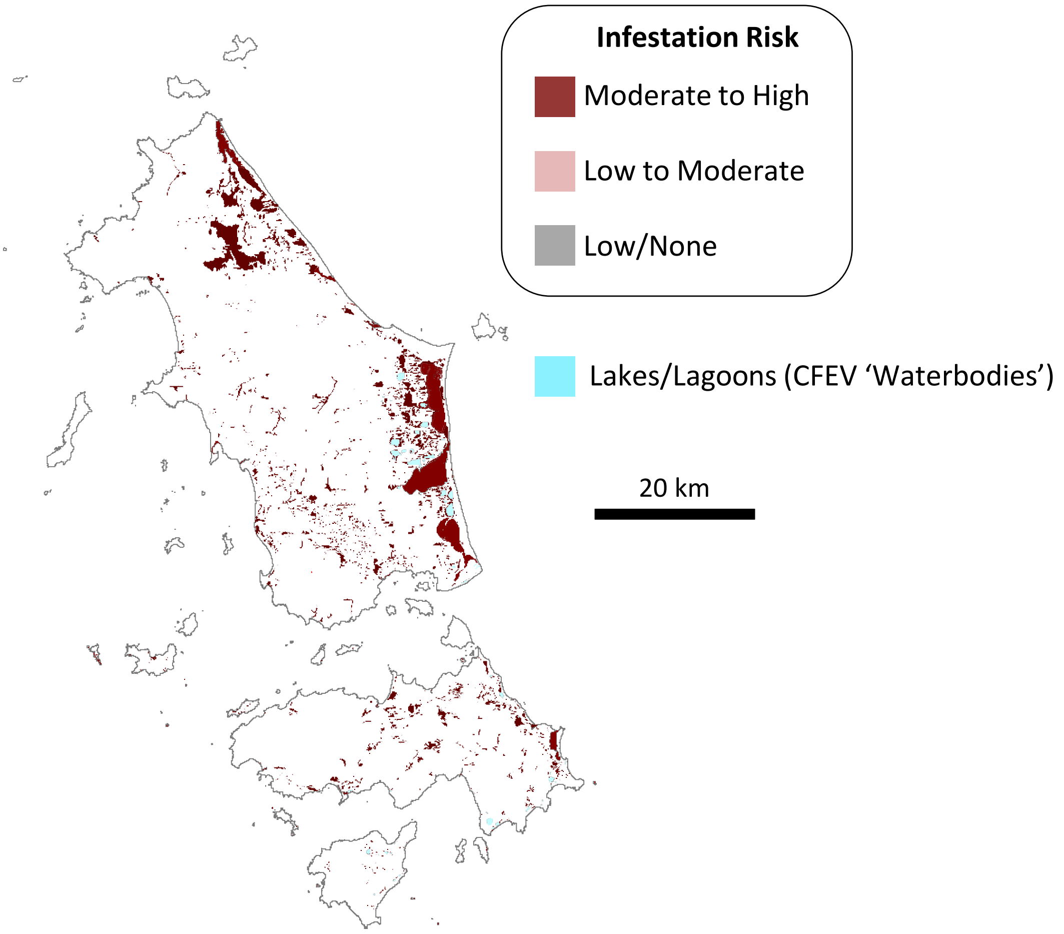


**Figure 9. Distribution of wetlands and estuaries on the Furneaux Island group, showing varying levels of hazard of Gambusia infestation following dispersal or translocation. Location of lakes and lagoons (CFEV 'waterbodies') shown for orientation.**

**Infestation Risk ratings: See caption of Figure 2.**

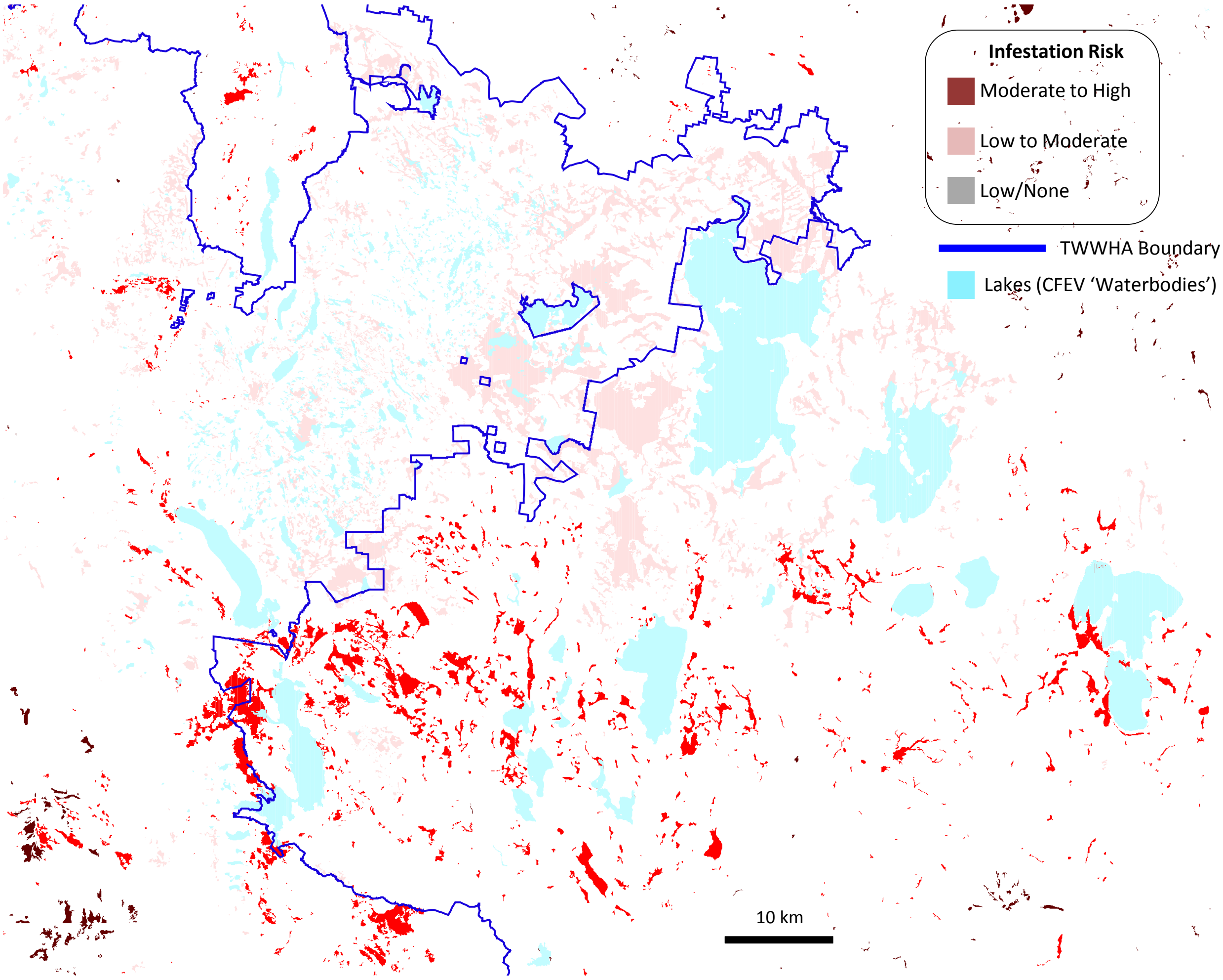


**Figure 10. Distribution of wetlands and estuaries in the Central Highlands area, showing varying levels of hazard of Gambusia infestation following dispersal or translocation. Location of lakes and lagoons (CFEV 'waterbodies') shown for orientation.**

**Infestation Risk ratings: See caption of Figure 2.**

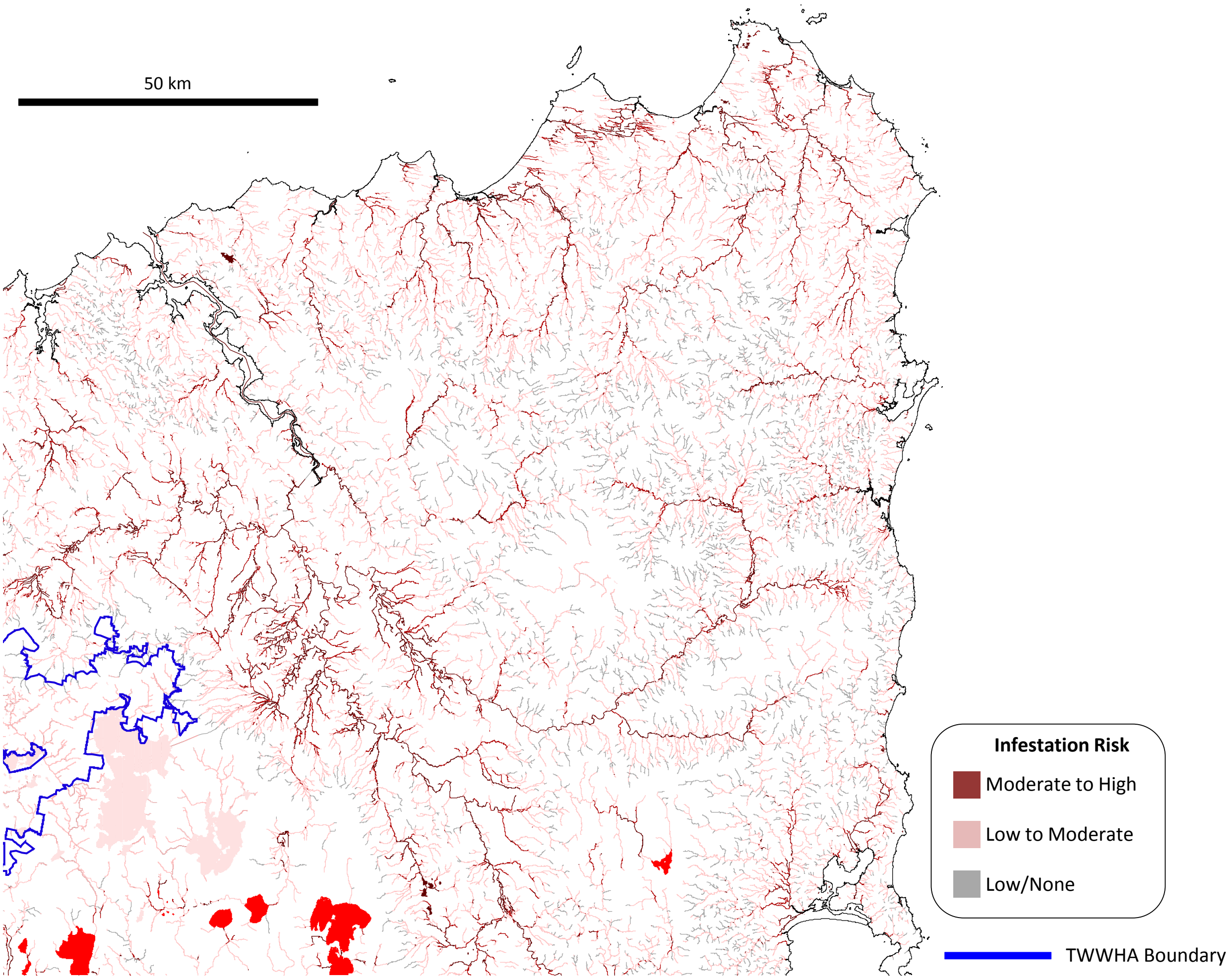


**Figure 11. Distribution of lakes and lagoons (CFEV 'waterbodies') and rivers in North East Tasmania, showing varying levels of hazard of Gambusia infestation following dispersal or translocation. Location of World Heritage Area boundary is shown for orientation. River lines of Strahler stream order 1 and 2 (small headwater tributaries, all rated as having low/no hazard) are not shown, for clarity.**

**Infestation Risk ratings: See caption of Figure 2.**

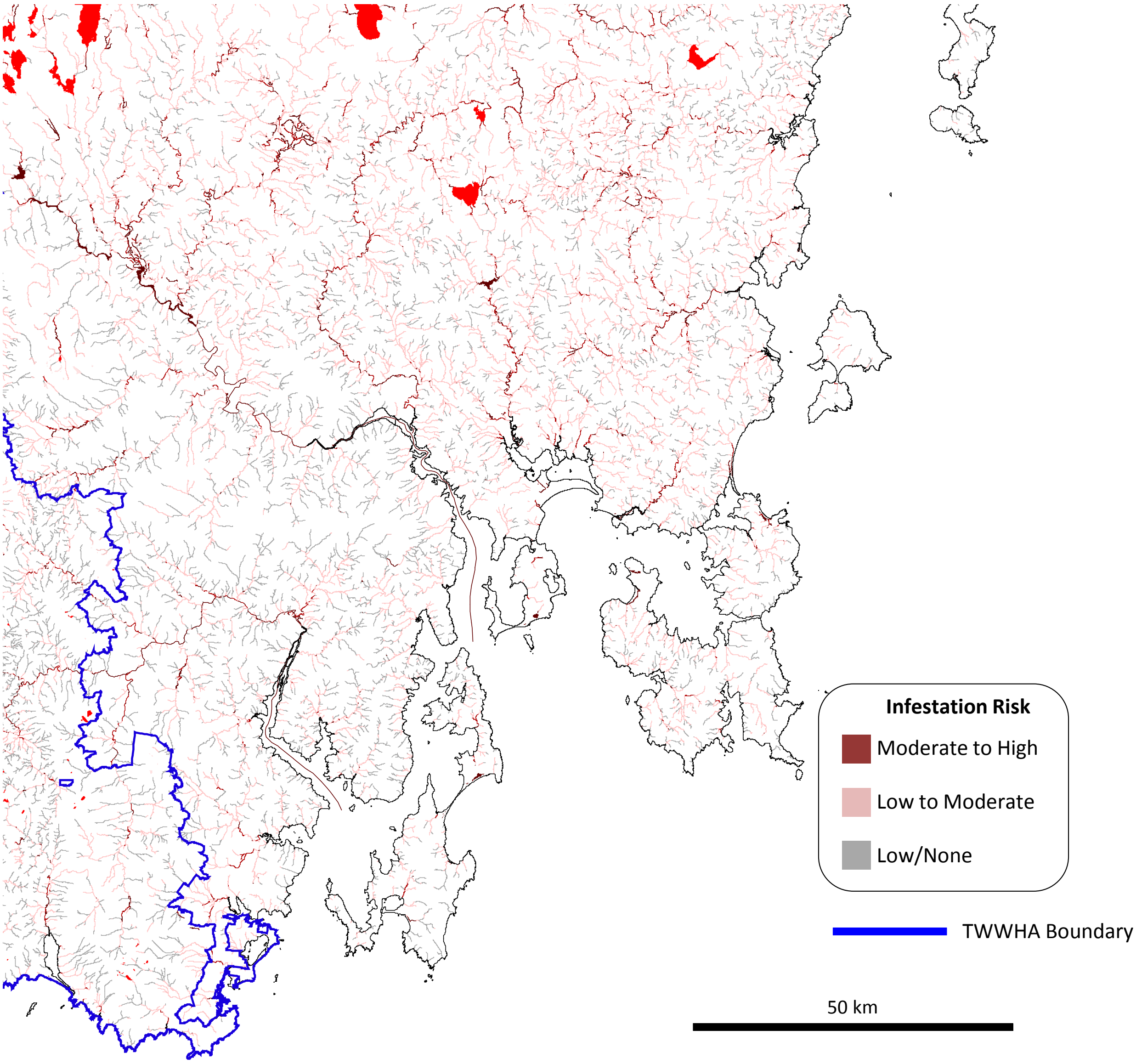


**Figure 12. Distribution of lakes and lagoons (CFEV 'waterbodies') and rivers in South East Tasmania, showing varying levels of hazard of Gambusia infestation following dispersal or translocation. Location of World Heritage Area boundary is shown for orientation. River lines of Strahler stream order 1 and 2 (small headwater tributaries, all rated as having low/no hazard) are not shown, for clarity.**

**Infestation Risk ratings: See caption of Figure 2.**

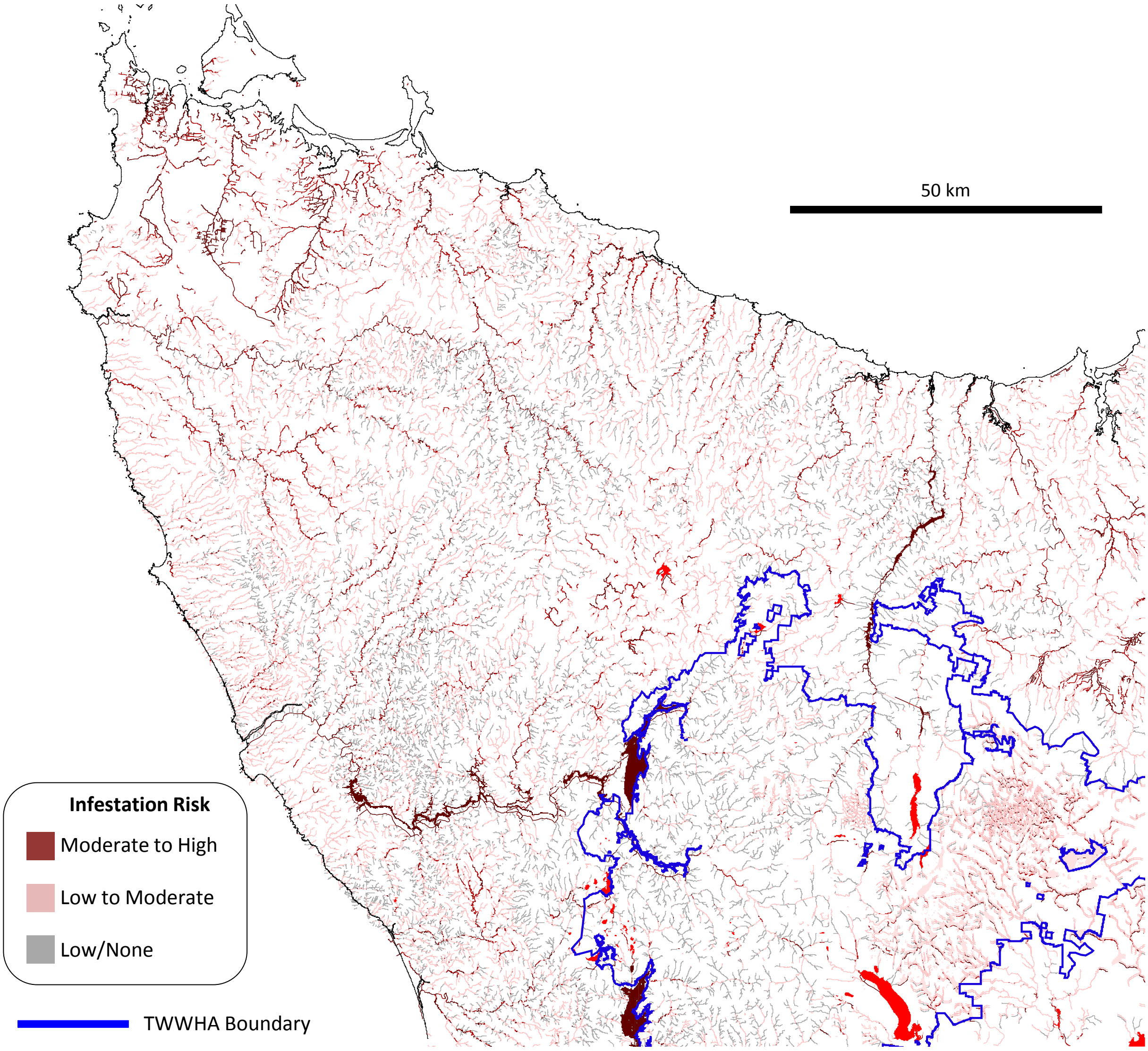


**Figure 13. Distribution of lakes and lagoons (CFEV 'waterbodies') and rivers in North West Tasmania, showing varying levels of hazard of Gambusia infestation following dispersal or translocation. Location of World Heritage Area boundary is shown for orientation. River lines of Strahler stream order 1 and 2 (small headwater tributaries, all rated as having low/no hazard) are not shown, for clarity. Drainage lines shown through lakes are a CFEV artifact and should be ignored.**

**Infestation Risk ratings: See caption of Figure 2.**

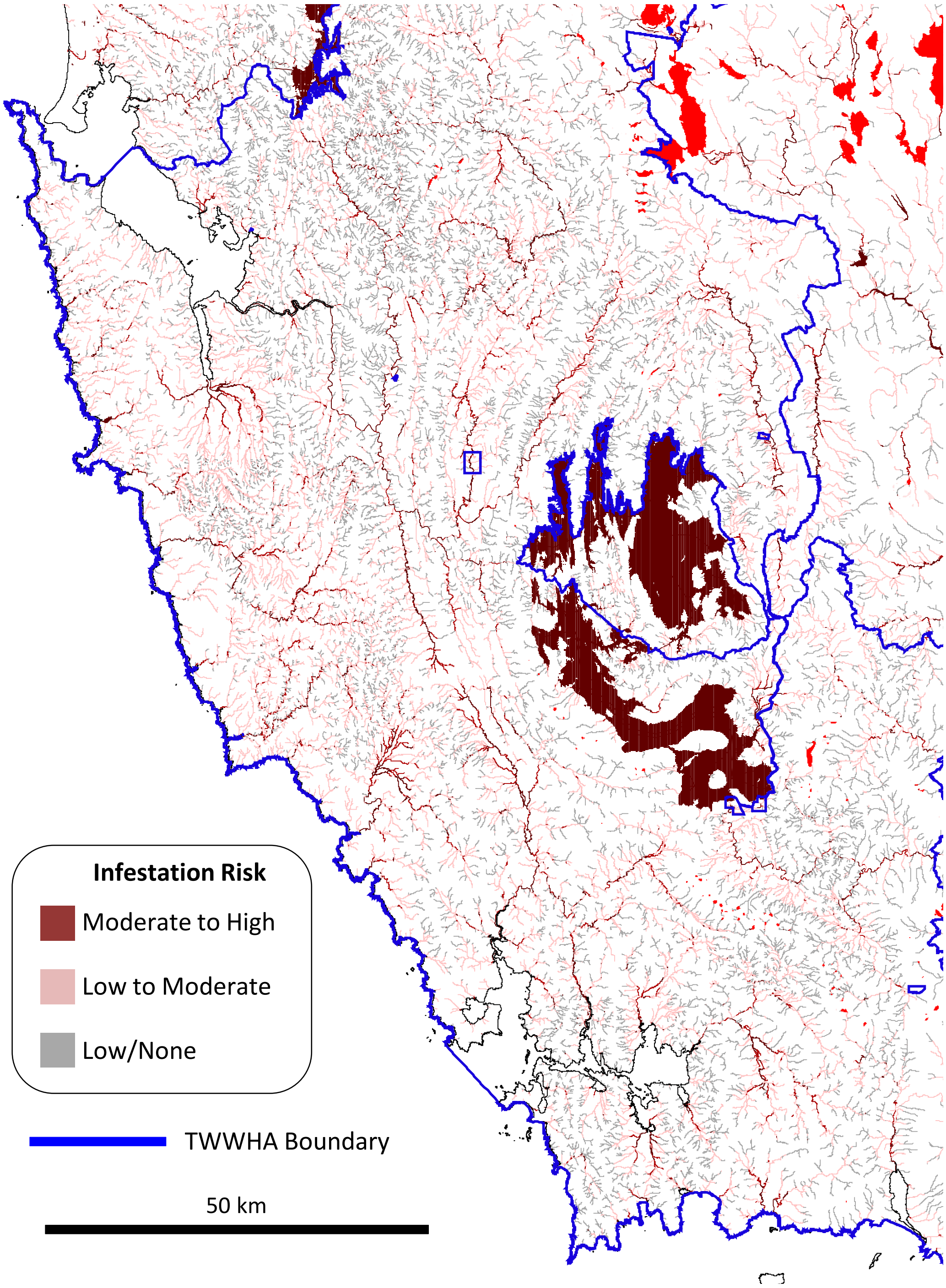


**Figure 14. Distribution of lakes and lagoons (CFEV 'waterbodies') and rivers in South West Tasmania, showing varying levels of hazard of Gambusia infestation following dispersal or translocation. Location of World Heritage Area boundary is shown for orientation. River lines of Strahler stream order 1 and 2 (small headwater tributaries, all rated as having low/no hazard) are not shown, for clarity. Drainage lines shown through lakes are a CFEV artifact and should be ignored.**

**Infestation Risk ratings: See caption of Figure 2.**

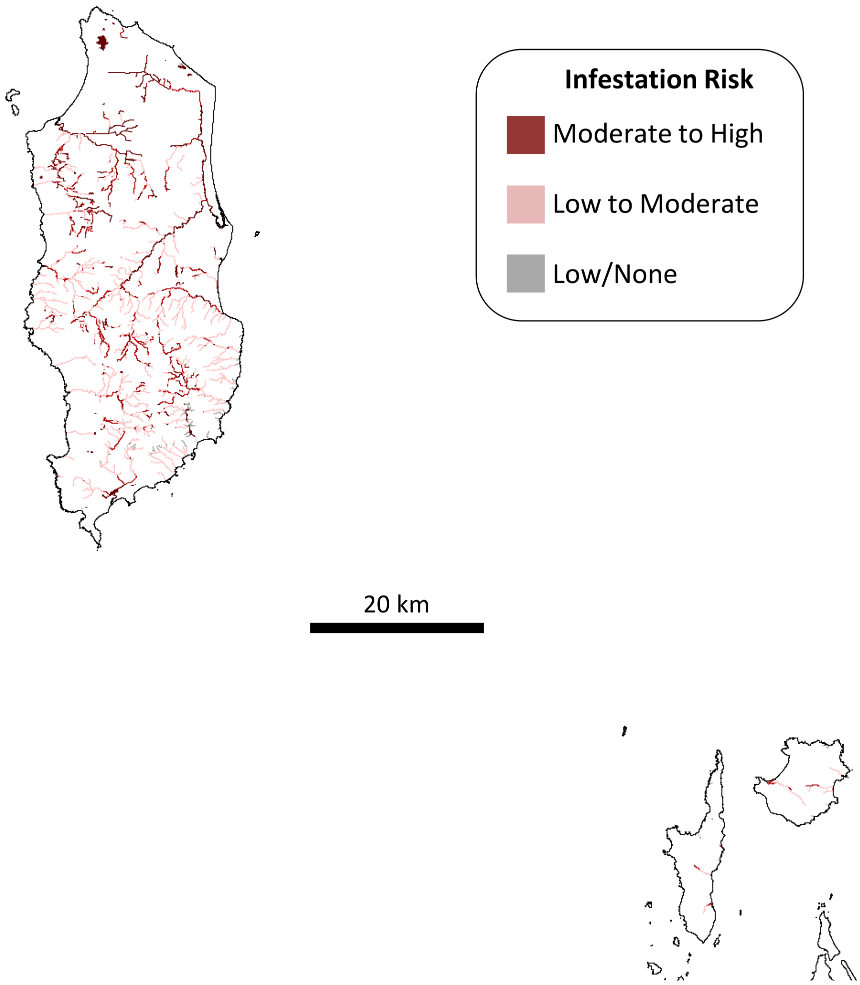


**Figure 15. Distribution of lakes and lagoons (CFEV 'waterbodies') and rivers on King, Hunter and Three Hummock Islands, showing varying levels of hazard of Gambusia infestation following dispersal or translocation. Location of lakes and lagoons (CFEV 'waterbodies') shown for orientation.**

**Infestation Risk ratings: See caption of Figure 2.**

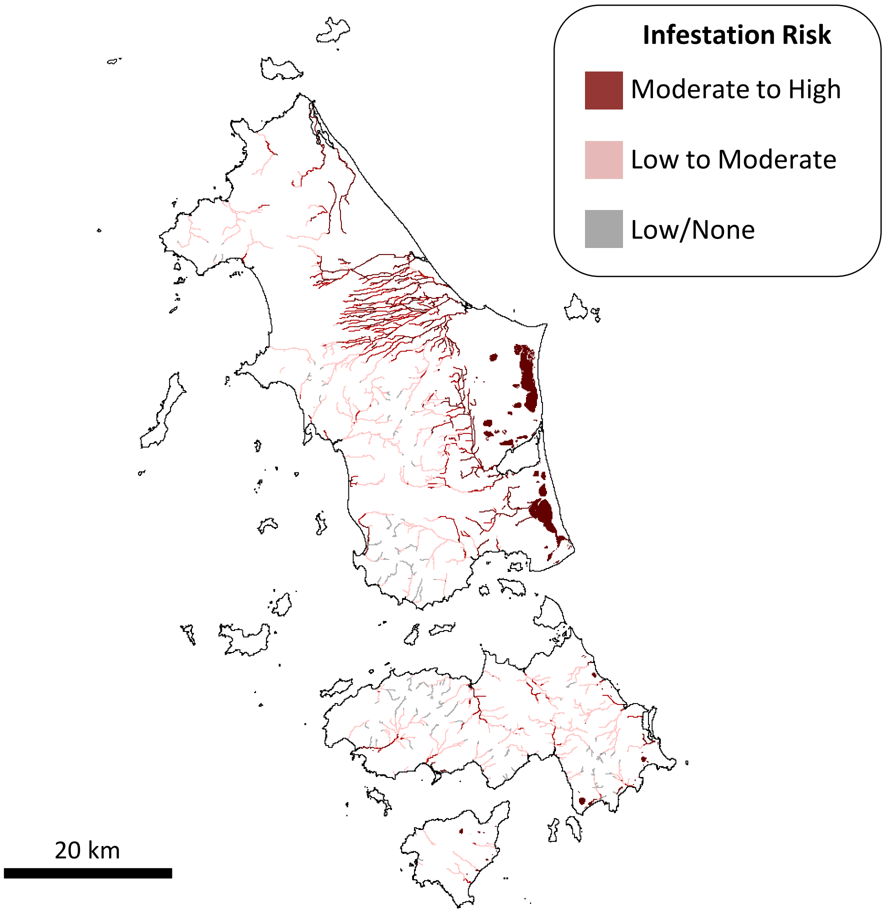


**Figure 16. Distribution of lakes and lagoons (CFEV 'waterbodies') and rivers on islands of the Furneaux group, showing varying levels of hazard of Gambusia infestation following dispersal or translocation. Location of lakes and lagoons (CFEV 'waterbodies') shown for orientation.**

**Infestation Risk ratings: See caption of Figure 2.**

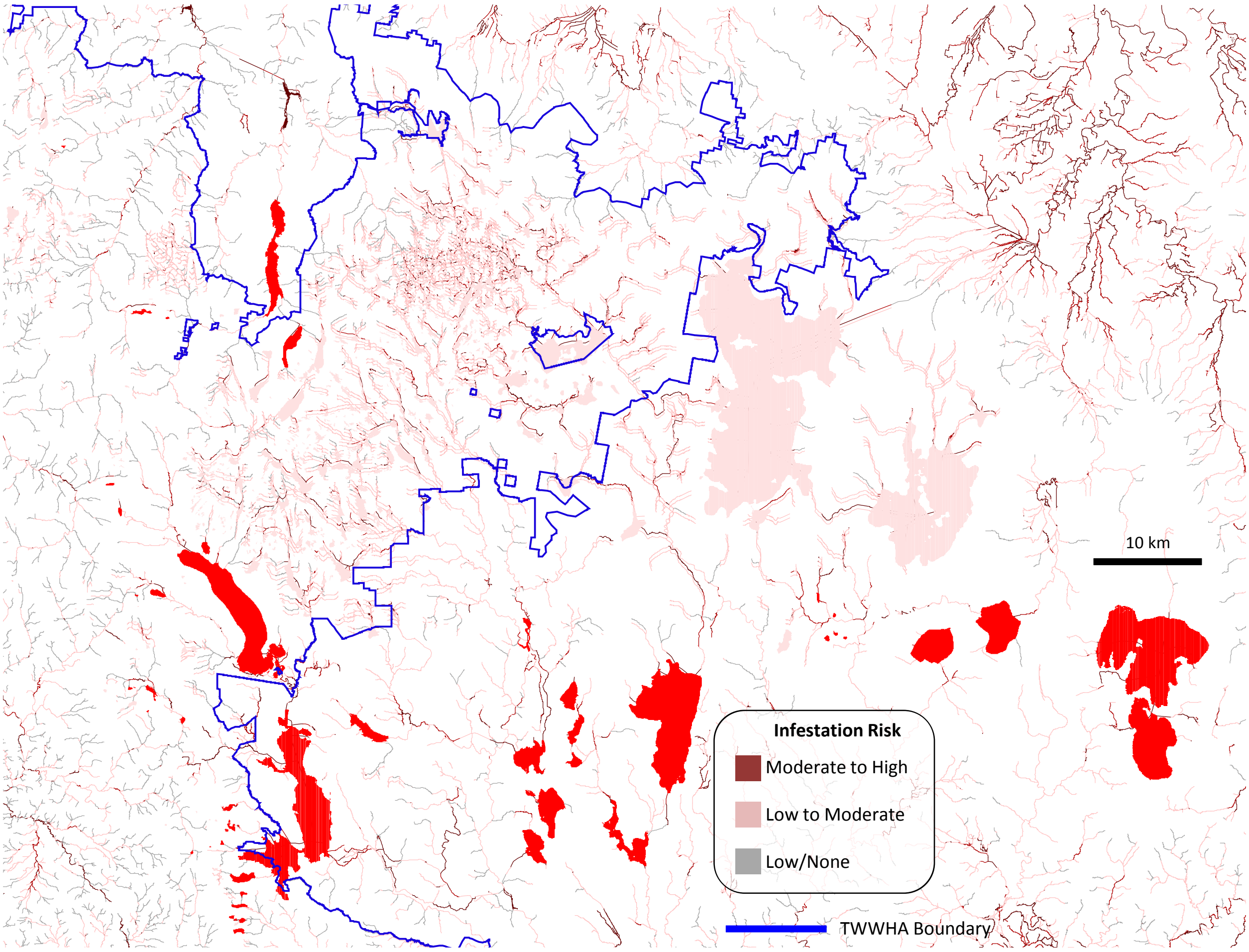


**Figure 17. Distribution of lakes and lagoons (CFEV 'waterbodies') and rivers in the Central Highlands, showing varying levels of hazard of Gambusia infestation following dispersal or translocation. Location of World Heritage Area boundary is shown for orientation. River lines of Strahler stream order 1 and 2 (small headwater tributaries, all rated as having low/no hazard) are not shown, for clarity. Drainage lines shown through lakes are a CFEV artifact and should be ignored.**

**Infestation Risk ratings: See caption of Figure 2.**